PHYSICAL GEOGRAPHY & GEOLOGY

L. DUDLEY STAMP

SENIOR BASIC TRAINING COLLEGE
BANIPUR.

~~1871~~

5376

5
4
39

SENIOR TRAINING COLLEGE
BANIPUR,

~~1871~~
5376

54
39

PHYSICAL GEOGRAPHY AND GEOLOGY

GEOGRAPHY FOR TO-DAY

A NEW SERIES OF GEOGRAPHIES

Book I. AT HOME AND ABROAD.
  A. Environments at Home.
  B. Environments Abroad.
  (Not published separately.)

Book I (Alternative). THE HOME ISLANDS.

Book II. THE SOUTHERN CONTINENTS.
  C. Australia and New Zealand.
  D. South America.
  E. Africa.

Book III. NORTH AMERICA AND ASIA.
  F. North America.
  G. Asia.

Book IV. EUROPE AND THE BRITISH ISLES.
  H. Europe.
  I. British Isles.

Book V. THE WORLD.

Additional Volume THE BRITISH COMMONWEALTH.

~~1871~~ S 39

Senior Basic Training College Banipur

PHYSICAL GEOGRAPHY AND GEOLOGY

~~5376~~

BY

L. DUDLEY STAMP, C.B.E., D.LIT., D.SC., F.G.S.

PROFESSOR OF SOCIAL GEOGRAPHY IN THE UNIVERSITY OF LONDON

With Maps and Illustrations

Library
25/3, B. C. Road
Calcutta

LONGMANS, GREEN AND CO
LONDON ◆ NEW YORK ◆ TORONTO

LONGMANS, GREEN AND CO LTD
6 & 7 CLIFFORD STREET LONDON W 1
BOSTON HOUSE STRAND STREET CAPE TOWN
531 LITTLE COLLINS STREET MELBOURNE

LONGMANS, GREEN AND CO INC
55 FIFTH AVENUE NEW YORK 3

LONGMANS, GREEN AND CO
20 CRANFIELD ROAD TORONTO 16

ORIENT LONGMANS LTD
CALCUTTA BOMBAY MADRAS
DELHI VIJAYAWADA DACCA

First Published	1938
New Impression .	*November*, 1939
New Impression .	*September*, 1941
New Impression . .	*March*, 1943
New Impression . .	*June*, 1944
New Impression .	*February*, 1952
Second Edition . .	*May*, 1953
New Impression .	*January*, 1956

[illegible] LIBRARY
Date........ 10.8.05
Accn. No. 11776

Made and printed in Great Britain by
William Clowes and Sons, Limited, London and Beccles

PREFACE

LIFE has become such a serious business for the modern schoolboy and the modern schoolmaster that there is little chance for the inclusion in the curriculum of any subjects falling outside the requirements of the General Certificate of Education. That test is a severe one, and every specialist teacher knows the struggle for sufficient time to deal adequately with his subject. Perhaps the remarkable increase in popularity in recent years of geography is due in no small measure to the wide scientific and cultural background of the subject. It touches many spheres, it throws or should throw light on many of the problems of the present-day world. Because of the breadth of his interests, the geographer perhaps tends to be superficial and too easily contented with second-hand knowledge and with the generalization of others. The study of the earth as the home of man should rest on an adequate knowledge of the crust of the earth itself. Geography should be built upon an accurate and adequate, even if limited, knowledge of geology. The evolution of man's occupancy of the earth's surface is but part of the whole story of the evolution of its animal and vegetable life, and there are thus links also with botany and zoology.

This little book is an attempt to place the foundations of modern geography upon a firm basis, to show the relationships with geology and with biology, and so, it is hoped, not only to strengthen the proper understanding of geography but also to arouse interest in the ever fascinating secrets of the earth itself.

It is intended to be used as an essential introduction or part of a certificate course in geography, or for the general principles and physical basis of geography courses for the first year of a university. The illustrations and examples have been drawn almost entirely from those known personally to the writer, and preference has been given to examples from the countries of the world where English is a medium of instruction, especially from the British Isles and India.

L. D. S.

NOTE TO THE SECOND EDITION

In this new edition a number of minor corrections have been made and I am greatly indebted to my collaborator on the Canadian Edition, Professor F. Kenneth Hare of McGill University, for his helpful suggestions.

L. D. S.

London,
February, 1953.

SENIOR BASIC TRAINING COLLEGE * RAMPUR

CONTENTS

CHAPTER PAGE
I. The Size and Shape of the Earth . . 1
II. The Composition and Origin of the Earth . 5
III. Denudation and Weathering . . . 13
IV. Transportation and Deposition . . . 44
V. Volcanoes and Volcanic Activity . . 65
VI. Earthquakes and Mountain Building . . 77
VII. Rocks and Minerals 96
VIII. The Atmosphere—Weather and Climate . 116
IX. Geomorphology 132
X. Soil and Underground Water . . . 160
XI. Vegetation and Animal Life . . . 165
XII. The Sea 187
XIII. The History of the Earth 194
XIV. The Physiography of the British Isles . . 217
Index 251

CHAPTER I

THE SIZE AND SHAPE OF THE EARTH

Geology and Geography.—The earth on which we live is a large spherical body. The science of geology (Greek *ge*=the earth, *logos*=learning or a discourse) is concerned especially with the character and composition of the earth—and in particular the materials which make up its visible crust—and with its long history, from its origin to the present day. Physical geography (Greek *ge*=the earth, *grapho*=I write) is concerned especially with the external form of the earth's crust and of the processes of change on the surface. But this is also an important part of geology, and so it is impossible to separate the two. The relationship between the underground structure and the surface features of the earth is really the special field of *geomorphology* (Greek *morphe*=form).

The Shape of the Earth.—The earth is not a true sphere, but is a sphere flattened at the poles, so that the *polar* diameter (*i.e.* the distance through the earth along its axis from the North Pole to the South Pole) is 7,899 miles, while the *equatorial* diameter is 7,926 miles. The earth's shape is therefore described more correctly as that of an *oblate spheroid*, but recent exact measurements have shown that there are certain variations from this regular shape, and so the earth is now frequently described as a *geoid*, *i.e.* an earth-shaped body. It seems at first that the numerous high mountains and great ocean deeps must render the whole very irregular, but the highest mountain is less than 30,000 feet—less than 6 miles—high and the greatest ocean deep only about 6 miles, so that the extreme variation of 12 miles is only 12 miles in a diameter of 8,000, or 0·15 per cent. Thus on a globe 2 feet in diameter the highest mountain would be correctly measured by a grain of sand $\frac{1}{400}$th of an inch high! Even the flattening of the earth at the poles would be difficult to see on a globe.

The Earth as a Sphere.—There are many ways in which it can be shown at once that the earth is a sphere. Men can travel round it in all directions; the shadow which it casts on the moon in the case of an eclipse is always circular; the range of vision (*i.e.* to the horizon) increases as we ascend; the masts of ships approaching from a distance are seen before the bulky hulls.

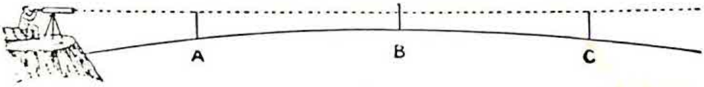


FIG. 1. Diagram to illustrate the Bedford Level Experiment

The amount of curvature can be measured—as it was long ago in what is called the Bedford Level experiment. In the quiet shallow stretch of water known as the Bedford Level in Britain's Fenland, poles were driven into the bed of the river so that they projected each the same distance above the level of the water. When, as shown in Fig. 1, the top of the third pole was sighted from the first it was found that the middle one projected above the line of vision. It is found that the apparent "drop" is 8 inches per mile. In two miles it would be

$8 \times 2^2 = 32$ inches, in three miles $8 \times 3^2 = 72$ inches. Thus a man 72 inches or 6 feet from his eye level to the ground at sea-level would be able to see the horizon 3 miles away. If he climbed to a height of 600 feet the horizon (*i.e.* where the water-surface and the sky appear to meet) would be 30 miles away ($8 \times 30^2 = 8 \times 900$ inches $= 600$ feet).

Latitude and Longitude.—Position on the surface of the earth is fixed by means of latitude and longitude. The line joining the North and South Pole through the centre of the earth is the axis about which it turns daily. If we imagine the earth split into two halves along this line, we could mark on the face of each half, taking the centre as the starting-point, the angles shown on Fig. 2.

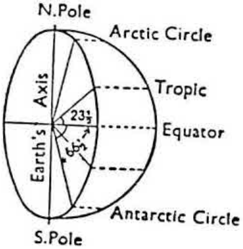


FIG. 2

Where the rays of the angular measurements strike the surface would be the latitudes. In other words, the latitude of a place on the earth's surface is the distance of that place north or south of the equator measured *as an angle* at the earth's centre.

In order to get the parallels of latitude we draw circles on the earth's surface taking the North and South Poles as centres. Notice that the parallels of latitude are parallel to one another and roughly the same distance apart, but that the actual circles get smaller and smaller as they approach the poles. It is roughly 25,000 miles round the equator (*i.e.* $2\pi r$, where r = radius of the earth, $2 \times 3{\cdot}14159 \times 4{,}000$ miles) but only 16,040 miles round the latitude of 50 (just south of Britain).

Thus latitude is angular distance north of the equator (north latitude) or south of the equator (south latitude).

Meridians of longitude are lines joining the North and South Poles and passing through the equator, which is divided into 360 degrees. By convention the line passing through Greenwich Observatory is used as the starting-point and is called the meridian of Greenwich (0°). From this central meridian we have east and west longitude until 180° is reached, exactly on the far side of the earth.

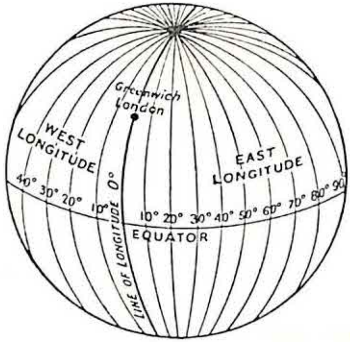


FIG. 3. Lines of Longitude

The Movements of the Earth.—The earth has two main movements. It turns round on its axis once in 24 hours, thus causing the phenomenon of day and night. Then the earth moves round the sun once a year. Its path round the sun is not a circle ; at some times the earth is nearer the sun than at others. Further, the earth's axis is always inclined to the plane of its orbit (see Fig. 111 below). In consequence the phenomena of the *seasons* result.

CHAPTER II

THE COMPOSITION AND ORIGIN OF THE EARTH

The Structure of the Earth.—The solid crust of the earth, on which we live and which forms the land masses as well as the floors of the ocean, is known as the *lithosphere* (Greek *lithos*=stone). It is composed of different *rocks*. The geologist and the geographer use the term " rock " not to indicate something hard but to denote the natural substances of the earth's crust whether they be hard or soft. Thus clay and sand are just as much rocks as granite or sandstone.

Because of the occurrence of volcanoes which erupt molten rock or *lava* at very high temperatures, it used to be thought that the interior of the earth was a mass of molten rock surrounded by a thin shell or skin, and that the folding of that skin was due to contraction as the interior mass cooled. If this were correct, the earth would probably become colder—of which there is little evidence. Physicists have shown that the centre of the earth must be a rigid solid and they have also been able to weigh the earth. It is found that the weight of the whole earth is 5½ times the weight of an equal mass of water, *i.e.* the earth's density is 5·5. But the average density of the rocks of the crust is only 2·5, so that to make up for this the central part of the earth has a density of about 7·0. For this reason it is called the *barysphere* (Greek *baros*=weight).

The barysphere is believed to consist mainly of iron, with a proportion of nickel and small quantities of other metals. Some of the meteorites which from time to time fall from space on to the surface of the earth have the same composition and consist of nickel-iron.

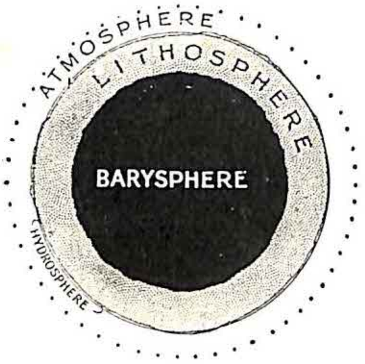


FIG. 4. The Earth

From observations on earthquakes it is calculated that the crust of the earth, or *lithosphere*, is from 700 to 1,000 miles thick. When a severe earthquake occurs, it gives rise to waves which pass: (*a*) along the surface of the earth; (*b*) directly, in a straight line through the crust; and (*c*) through the crust to the surface of the barysphere, where they are reflected. Thus at the seismographs of a distant station three separate shocks are received. This is explained in Fig. 5.

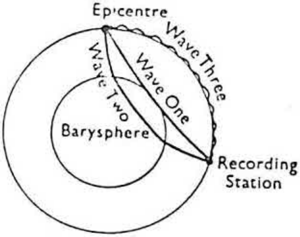


FIG. 5. Propagation of Earthquake Waves through the Earth's Crust

The *lithosphere* itself is believed to consist of several layers or shells. Below the layer of sedimentary rocks on the surface is a layer (the outer silicate zone—sial or sal), which has about the same composition as granite. Below this is a layer of denser rocks (the inner silicate zone or sima) about the composition of basalt, and below this a mixed zone. In addition it seems that the rocks underlying the great oceans are denser than those under the continents (see below, p. 11).

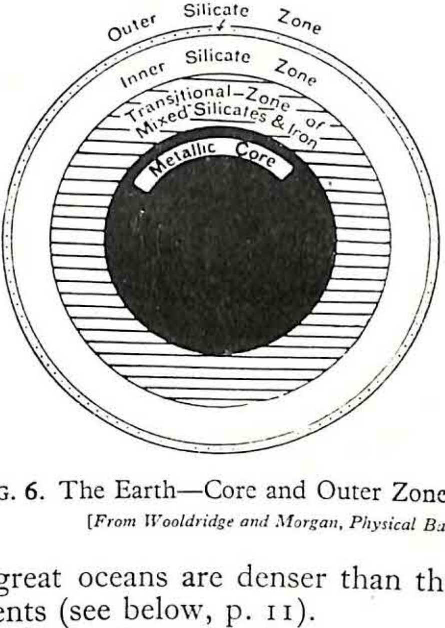


FIG. 6. The Earth—Core and Outer Zones

[*From Wooldridge and Morgan, Physical Basis of Geography*

The envelope of water—the oceans and seas—which partly surrounds and obscures the lithosphere is sometimes called the *hydrosphere* (Greek *hudor* = water). Then surrounding the whole is the mixture of gases which we call the air or *atmosphere*.

Physical geography is concerned with each of these four divisions, but especially with what takes place on the surface of the earth where atmosphere, hydrosphere, and lithosphere meet.

The Origin of the Earth.—The earth is one of the *planets*, and all the sister-planets (of which the chief are Mercury and Venus, which are nearer the sun, Mars, Jupiter, Saturn, Uranus, and Neptune, which are farther away from the sun) likewise travel round the sun, thus constituting what is known as the Solar System. The sun itself is an enormous mass of hot vapours approximately 93,000,000 miles from the earth and having a diameter of about 865,000

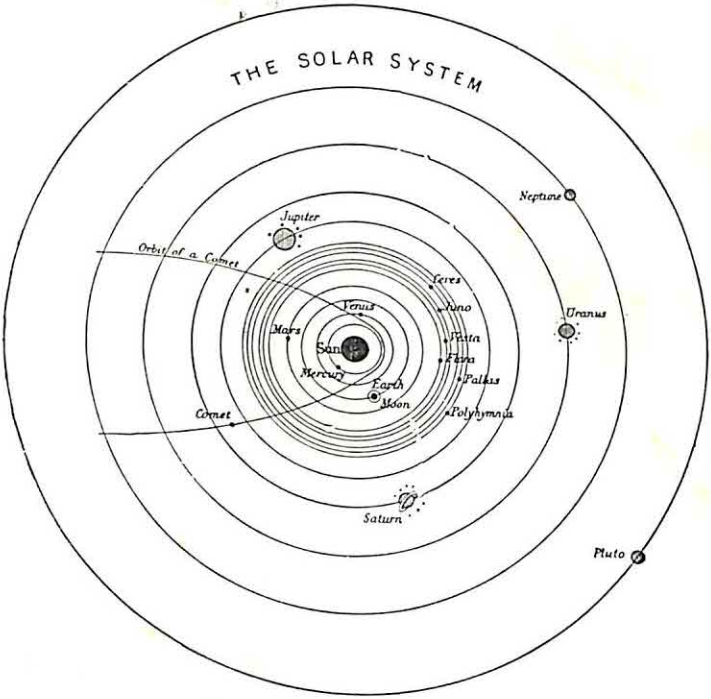


FIG. 7. The Solar System

miles. Yet our sun is only one of many, many suns which exist and appear to us as stars. It is thus by observing the stars that we get some clues as to the origin of the earth, and especially by observing the cloudy masses or nebulæ which seem to be solar systems in process of formation.

According to the *planetismal hypothesis* swarms of meteorites or tiny planets, probably torn out of the sun's mass by the disruptive action of a passing star, whirling round the sun gradually coalesced to form a limited number of planets. So the earth must have grown by the gradual fusion of enormous numbers of meteorites. Some believe that they fused at very, very high temperatures (meteoric hypothesis), others that they came together when comparatively cold. Some believe that the crust or lithosphere was formed as a sort of scum or froth on the surface of the molten mass ; others that this represents a later stage in the growth of the planet after the central metallic core had been formed.

According to the older *nebular hypothesis* the temperatures of the masses whirling round the centre were so high that any substances were in the form of luminous gases. The gases gradually gathered round certain nuclei and cooled to form white-hot molten masses which in turn cooled gradually to form planets with a surface sufficiently cool and solid to support life (at least in the case of the earth). In some cases the planets have thrown off satellite bodies. The earth has one such satellite, the moon, which has a diameter of only 2,163 miles and revolves round the earth at a distance of roughly 240,000 miles. When the moon, in the course of its journey round the earth, comes directly between the earth and the sun so that the sun is obscured from our view, a *solar eclipse* results. When the earth comes between the sun and the moon and so casts a circular shadow on the moon, a *lunar eclipse* results.

Deformation of the Earth.—The old idea that the earth was gradually shrinking by becoming cooler has been upset by the discovery of radioactivity—that mineral substances by slow change (the radiation of minute particles) can actually generate heat and thus maintain the temperature of the crust. It used to be thought that certain areas of very ancient rock constituted parts of the original crust of the earth, and it used also to be thought that these constituted the stable "corners" about which the earth was shrinking (*tetrahedral theory*). We now know that these areas of ancient rock are not part of the original crust and have themselves a long and complex history. There are, however, parts of the earth's crust which form relatively "stable blocks," and it is *between* these that the great folding and mountain-building movements take place. According to *Wegener's Hypothesis of Continental Drift*, these great continental blocks are capable of drifting—drifting towards one another or away from one another.

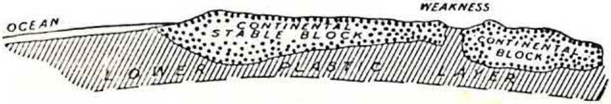


FIG. 8. Interpretation of Isostasy

The theory of continental drift is obviously closely connected with the older and well-established theory of *isostasy* and compensation. The great continental masses are conceived as relatively light masses floating on a heavier substratum (which underlies the great oceans), and the greater thickness of the crust over the lands is compensated for by the greater density of the rock under the ocean. The differences in gravity have been proved.

The Earth's Major Relief.—There are certain features of the earth's surface which seem to confirm the conception of isostasy. As far as evidence is available it seems that the great oceans are permanent features and that probably the floors of these oceans have never been dry land. The continents have at times been submerged below the level of the sea, but never to great depths. Round the margins of the continents we find shallow *epicontinental seas* or a belt of varying width of shallow water below which is the *continental shelf*. Then there is a somewhat abrupt or steep slope to the undulating floor of the ocean at a depth of about 12,000 feet. Just as the surface of the land lies mainly between sea-level and 5,000 feet and is only rarely interrupted by great mountain chains, so the floor of the ocean between 6,000 and 18,000 feet (1,000 and 3,000 fathoms) is only rarely interrupted by great ocean deeps.

Rocks and Minerals.—We have already explained that the earth's crust is built up of various *rocks* which may be hard or soft. Granite, sandstone, slate, chalk, clay, shale, sand, and mud are all examples of rocks. We find that they vary greatly in character and composition. Thus if we examine granite we find that it consists of reddish, pinkish, or yellowish fragments or crystals (felspar), shiny flakes of mica, and a glassy material (quartz). The proportion varies and each of these separate constituents is a *mineral*. Similarly if we examine sand under a microscope we find that it consists of grains of very varied size. Many of these are again colourless grains of quartz, but there are other grains entirely different. So, again, sand consists of a variable mixture of different minerals. A rock, then, is a naturally occurring substance with certain definite physical characters which can be seen and described—colour, texture, weight, etc.—but which if analysed chemically is found to vary greatly. Most rocks are built up of a variety of minerals, and we find if we examine a mineral it not only has constant *physical* characters but also, if analysed chemically, it has a constant *chemical* composition or a chemical composition which varies between narrow limits. Each mineral can be given a chemical formula to represent its composition. Thus silica is silicon dioxide (SiO_2); felspar, though much more complicated, is a silicate of potassium (or sodium and calcium) and aluminium (aluminum) varying within certain limits.

CHAPTER III

DENUDATION AND WEATHERING

General.—Everybody knows what we mean by a "weather-beaten" building. After a few years' exposure to the sun, wind, and rain a garden seat becomes rotten, the nails rust, and it falls to pieces. Sheds and wooden buildings we paint or tar to protect them from the weather. Even brick or stone houses suffer from the weather; the stones change colour and take on a mellowed appearance, sometimes fragments flake off in winter and the mortar flakes away so that the walls have to be repointed with fresh mortar. In the same way the earth's crust, as soon as it is brought above the level of the water of the sea, begins to get worn away by the agents of *atmospheric weathering*. This is *only part* of the process of *denudation* (Lat. *denudo* = to lay bare) when the surface is worn away and lower layers exposed, for there are other powerful denuding agents besides the weather. The sea, for example, wears away the rocks along its margin. This and the action of rivers and glaciers (rivers of ice) in deepening or widening their valleys is often called *erosion* (Lat. *erodo* = to gnaw away) or *corrasion* (Lat. *corrado* = to rub away) and so is another example of denudation. We can now consider the various forces of denudation, including weathering and erosion.

The Action of the Sun.—When an object is placed in the direct rays of the sun it naturally becomes hot. Most substances when heated expand,

and this is true of the rocks and minerals which make up the crust of the earth. Thus when a surface of bare rock is exposed to the rays of the sun, the upper layers become greatly heated, whilst the lower layers are scarcely affected. The heated upper layers cannot expand laterally or downwards, and can only expand upwards by breaking away from the main mass. This actually is the effect of exposure to the rays of the sun or *insolation*, that a surface layer of rock is split off, rather like the skin of an onion. The process is most marked when the rocks are unprotected by a surface layer of soil or vegetation and so is specially important in desert regions. In these same regions there is a great contrast between the heat of the day and the cold of the still clear night, when radiation is rapid; and the very rapidity of heating and cooling, and so of the forces of expansion and contraction, hastens the splitting of the rocks. At high levels—on lofty plateaus such as those of Tibet or the Andes—where the atmosphere is rarefied, the sun's rays are very powerful. A rock exposed to the sun may be too hot to touch, whilst a pool of water in the shade may still be frozen. The same is true on high mountains, so that here also the action of the sun is powerful. In some cases it would seem that a shower of cold rain on heated rocks may hasten the process. In countries subjected to the sun's action the air may sometimes resound as with the noise of pistol shots—especially in the late afternoon when

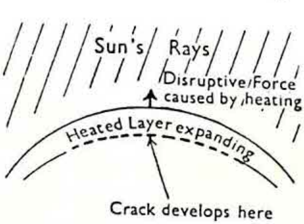
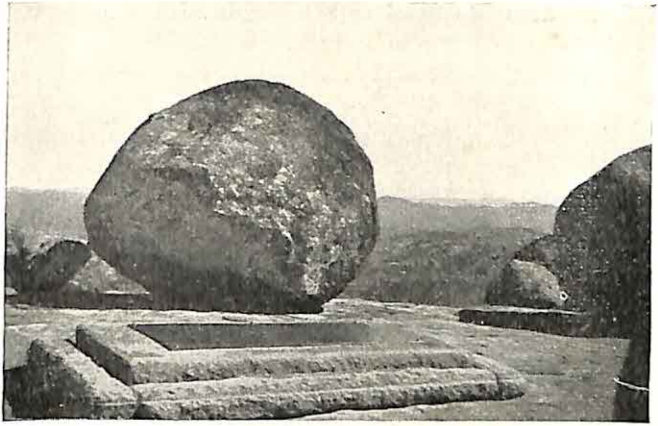


FIG. 9. Diagram showing the Action of Sun's Heat

sudden cooling sets in—caused by the sudden breaking off or exfoliation of the heated layers.

Naturally the fragments broken off are jagged and angular, though the main mass from which the "skins" of rock have been broken off may be smooth as shown in Fig. 10. This photograph shows also that a "core" of rock may be left—to be gradually made smaller—which is almost a perfect sphere. Owing to the succession of "skins" which are peeled off this is often called "onion weathering" or "spheroidal weathering."



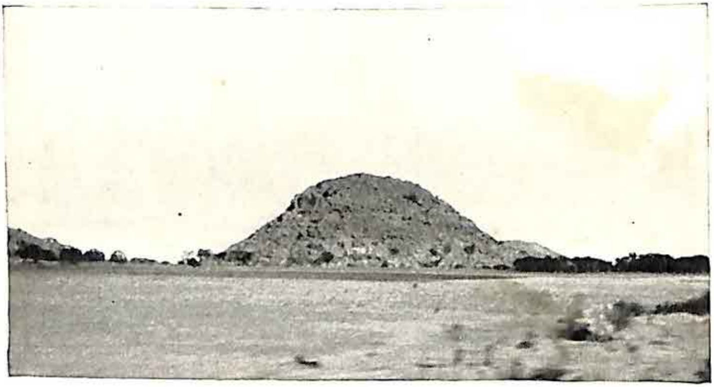
[*Photo: L. D. Stamp*

FIG. 10. Weathering of Granite due to Insolation, Matopo Hills, Rhodesia

In the foreground is the grave of Cecil John Rhodes, who asked to be buried in this lonely spot, but the boulders are natural and untouched.

The process does not end with the splitting off of the fragments. Most rocks are composed of a variety of minerals which expand at different rates, and so cause a disruption of the rock fragments into angular sand. A coarse-grained rock such as granite is particularly liable to be broken up in this way. A very common feature in hot lands is to find a small island-like mass of rock (German: *inselberg* =island mountain) surrounded by an almost level sea of sand, the whole caused almost entirely by the sun's action.

Although the action of the sun is less important in cooler and damper lands, the sun has several indirect influences in high latitudes and in mountainous country. There "a place in the sun" may be essential for human life and for the cultivation of crops, so that the location of farms and villages amongst the mountains is often dependent upon the sun, sites being selected which are well placed to receive the sun's rays. Here cultivation may arrest the natural weathering action of the sun

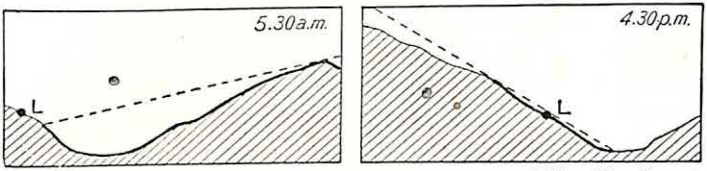


[*Photo: L. D. Stamp*

FIG. 11. An "Inselberg" at Kupgat, near Raichur, Hyderabad, India.

The hill shows also the characteristic weathering of granite.

and the cultivated stretches form islands in country of a much more rugged character.

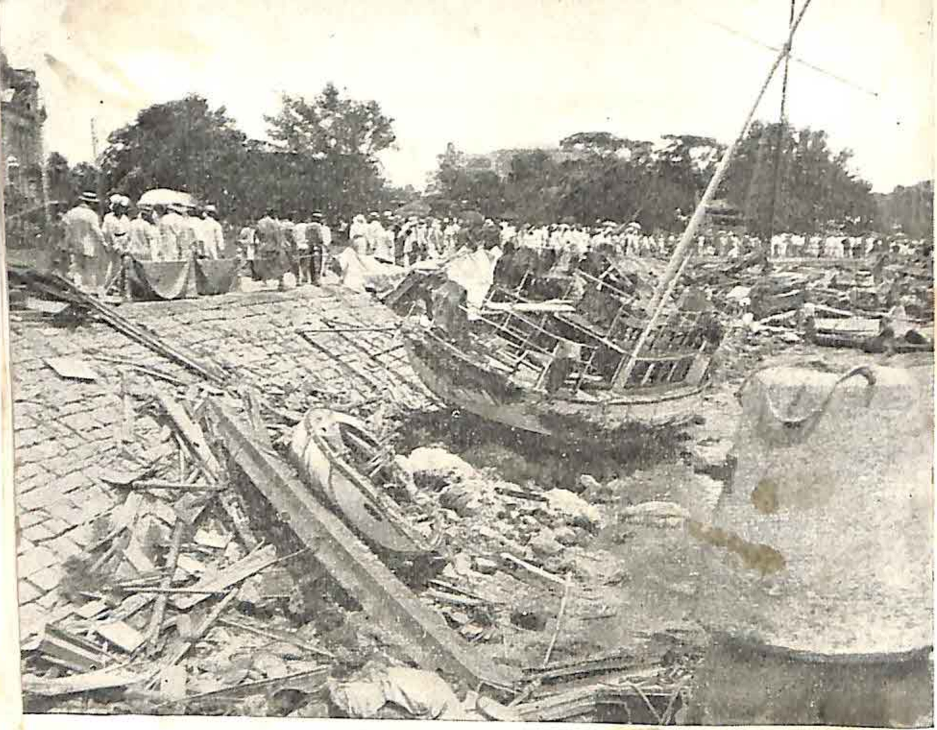


[*After Alice Garnett*

FIG. 12. Insolation of Swiss Valley.

The parts shown by a dark line are in shadow at the time indicated. The town L can receive a maximum of only 11 hours of sunshine on the day shown (midsummer day) against a possible maximum of 16 hours for a place on the plains in the same latitude.

The Action of Wind.—Although wind plays an important part in weathering its action is largely indirect. Sometimes the wind itself is sufficiently powerful to cause considerable damage (as in tropical cyclones, hurricanes, and typhoons) and quite large fragments of rock as well as trees, etc., may be moved. Wind removes loose sand and dust from cliffs and from around exposed rocks, leaving fresh surfaces exposed to the action of other weathering agents. The action of the wind itself is greatly increased when it is armed with sharp particles of sand. The surfaces of hard rocks are cut or polished in this way, and it is often possible to tell the direction of the prevalent winds in rocky deserts as the rocks are all polished on the windward side. Sometimes winds from more than one direction wear and polish pebbles so that two or more polished surfaces meet in sharp edges. Pebbles with three such facets (dreikanter) are common in many deserts. Naturally the wind is most effectively armed with sand as it blows along near the ground,



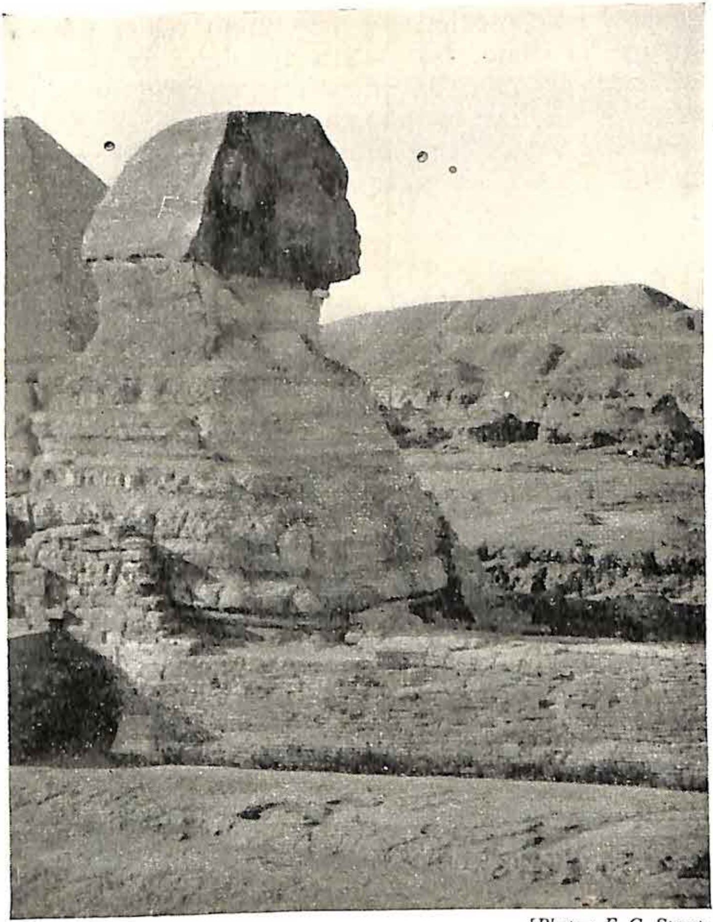
[Photo : E. N. A.

FIG. 13. Wind action: the Bund at Shanghai littered with broken boats after a typhoon

and there the cutting action when it meets an obstacle is greatest. Thus cliffs are undercut by wind action and eventually the overhanging masses crash to the ground.

Particles of sand rolled along by wind action are rubbed against one another and become rounded. This process goes on until the grains are entirely worn away, and one of the distinguishing characteristics of desert sand is that it includes at least a proportion of well-rounded and polished grains even amongst the very smallest.

Wind erosion has assumed enormous importance



[*Photo : E. C. Stamp*

FIG. 14. The Sphinx

An example of polishing and undercutting by wind action. The base and feet were covered with sand and so protected, but the neck and face were exposed and, although of hard rock, have been polished and partly worn away during 3,000 years of wind action.

in recent years in dry cultivated regions. Where the soil is protected by vegetation or crops little damage is done, but when the land is ploughed and exposed, the entire soil may be removed as dust. This has happened in parts of the middle western states of the U.S.A. and in the drier parts of Saskatchewan, as well as in Africa.

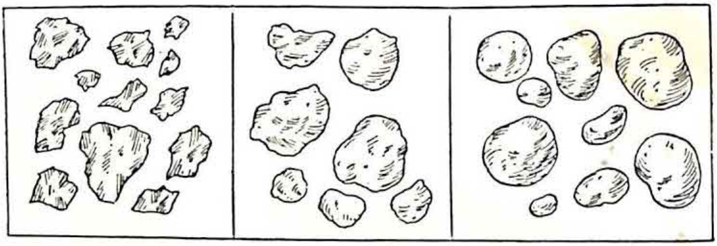
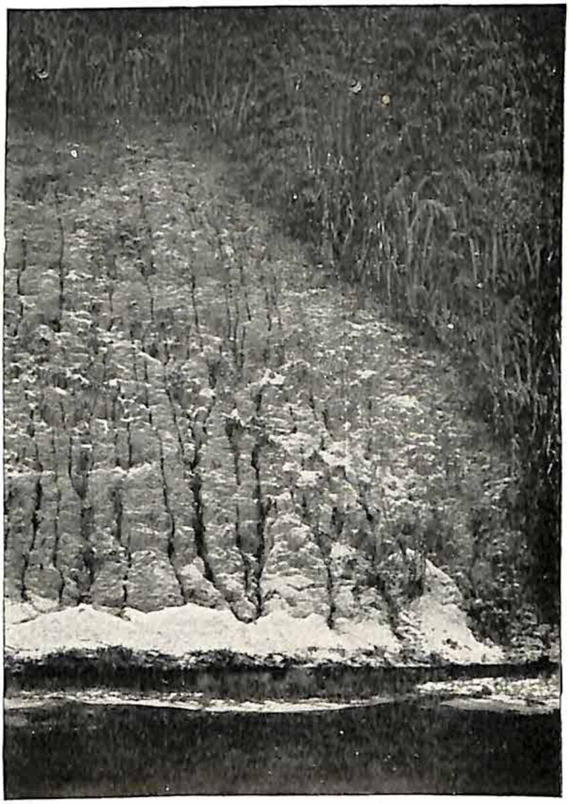


FIG. 15.

Glacial Sand from under the Rhone Glacier — Normal Sea or River Sand — Desert Sand

The Action of Rain.—The weathering action of rain is both mechanical and chemical. The *mechanical* action takes several forms and occurs wherever rain falls. It is perhaps best seen in dry countries where the rain comes in occasional heavy downpours, and rapidly wears away deposits of loose sand; where stones or hard masses of rock occur in such loose deposits, they protect the underlying sands, and "earth pillars" may be formed. On the other hand, rain may have just the reverse effect by beating down the surface of the ground and forming a hard protective layer. In cultivated ground in regions of heavy rainfall (as in the tropics) the rain tends to wash out the finer particles

1871 39



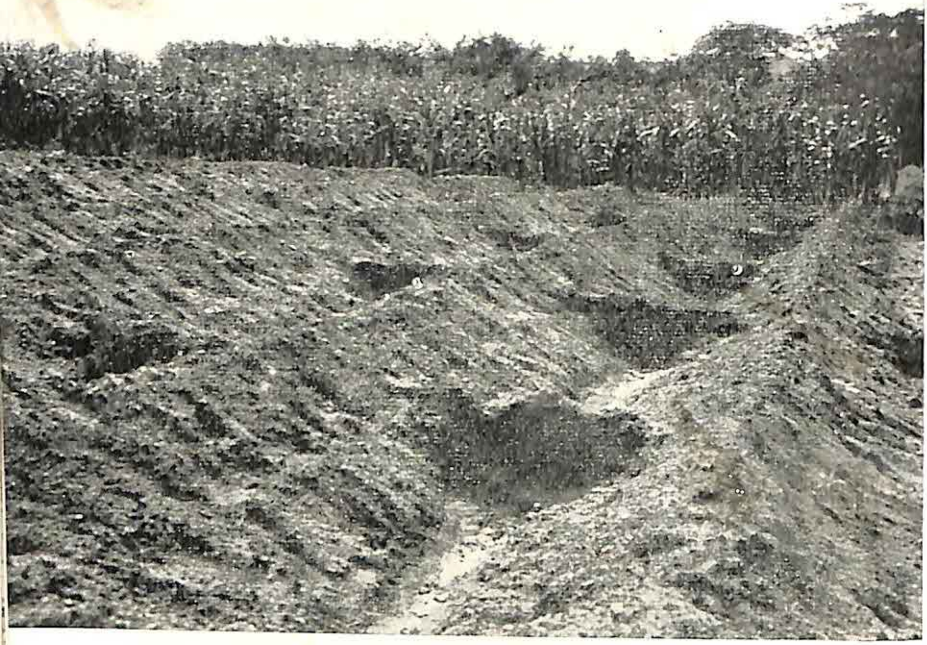
[*Photo : L. D. Stamp*

FIG. 16. Denudation of Soft Deposits by the Mechanical Action of Rain, Roadside Cutting, Calabar, Nigeria

On the right, denudation has been prevented by the vegetation covering.

S.C.E.R.T., W.B. LIBRARY
Date 10.8.05
Acc. No. 11776

S.C.E.R.T. Library
25/3, B. C. Road



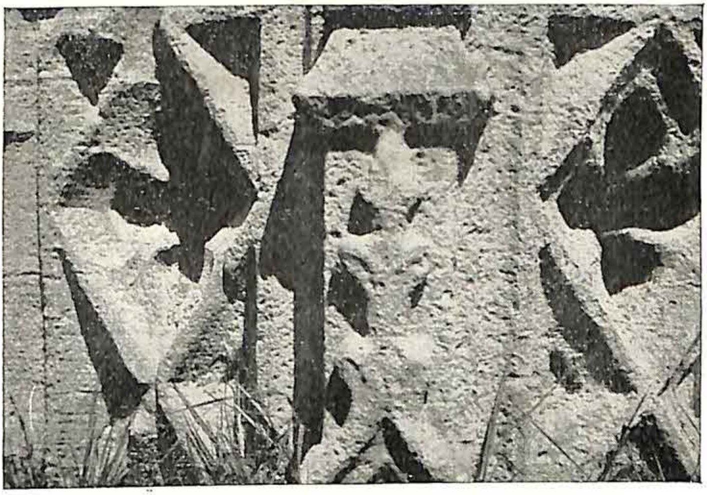
[Photo : L. D. Stamp

FIG. 17. Basin Cultivation in Nigeria

of the soil and to leave behind the coarser, and it is one of the problems of soil erosion control to prevent the washing away of this valuable fine material. One way of doing this is in the basin type of cultivation found in tropical Africa (Fig. 17), where the fine particles are simply washed into the little basins.

The mechanical action of rain naturally varies with the type of rock on which the rain falls. With porous rocks (*e.g.* limestone and sandstone) the water sinks into the ground and washes the finer particles to lower levels; with impervious rocks (*e.g.* clay) it moves off the surface.

When the drops of rain pass through the atmosphere they absorb certain of the gases contained in the atmosphere, notably carbon dioxide (CO_2), and so the rain becomes weak carbonic acid (H_2CO_3) capable of dissolving certain minerals, notably calcium carbonate or limestone. Thus limestone is gradually dissolved away, a phenomenon which may be seen on limestone buildings. The process is hastened in cities where the air contains minute



[*Photo : L. D. Stamp*

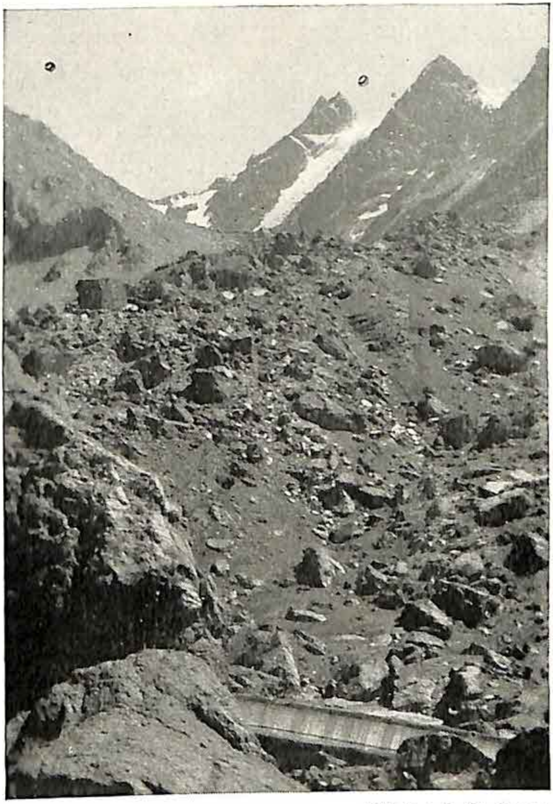
FIG. 18. A Stone from the British Houses of Parliament after 70 Years of Weathering in London Atmosphere (Principally the Chemical Action of Rain)

quantities of other gases even including sulphur dioxide (SO_2) so that the rain water becomes weakly charged with sulphurous and even sulphuric acid. Some building stones which weather very slowly under normal conditions break up very quickly in cities. This is the case with the magnesian limestone of which the Houses of Parliament are built

Many rocks change colour under the influence of the weather—the usual change being to reds or browns due to the oxidation of iron salts. Thus London clay is blue-black where found in deep pits, brown when seen at the surface.

The chemical action of rain is really more important just underground than it is at the surface. Soluble salts are washed downwards in the soil—a process known as leaching—sometimes to such an extent as to render the surface layers almost devoid of soluble salts. Thus soils overlying limestone are sometimes almost entirely free of lime. Further, the water percolating underground may produce solution-hollows, and caverns.

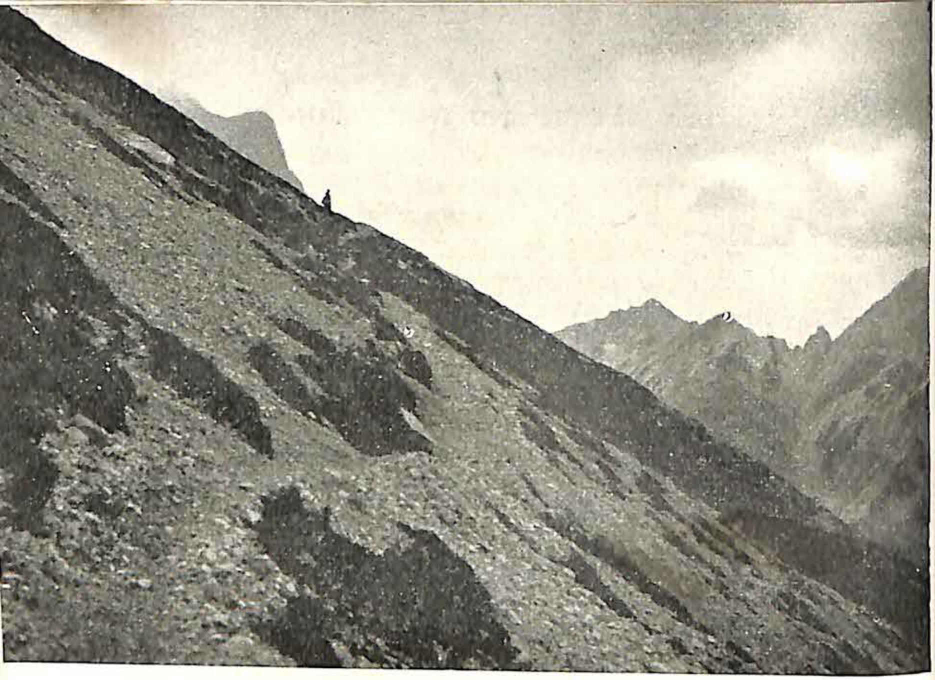
The Action of Frost.—The action of frost depends upon the fact that when water is changed to ice by freezing (at a temperature of freezing or 32° F. or 0° C.) the water expands. When the ice melts, contraction takes place. Thus when a crack in a rock is filled with rain water and the water freezes, the water expands and the crack is widened. A thaw follows, but again the crack fills with water, freezes and is further widened. Gradually angular fragments of rock are split off and even great masses may be disrupted. Naturally the action of frost is most marked in high mountains. There the rugged, angular crags owe their general characters to frost action, and the sharp-sided fragments of very varied size which are split off fall to the foot of the mountain to form *screes* which are really natural tip-heaps of rock fragments dislodged by frost. Until an old scree is slowly "fixed" by vegetation, the fragments are unconsolidated and the removal of one block may cause a great mass to slide. Thus mountain climbers avoid screes when



[*Photo : L. D. Stamp*

FIG. 19. The Action of Frost and the Formation of Screes

A typical Scree in the High Andes of Argentina at 10,000 feet above sea-level. The strong wooden "sheds" in the foreground protect the Trans-Andine Railway from snowdrifts and falling stones. Photo taken in January (midsummer).



[*Photo : L. D. Stamp*

FIG. 20. A Scree Partly Fixed by Vegetation, Slovenia

Illustrating the "angle of rest" of a scree.

ascending, though they may use screes when descending.

The action of frost is not by any means restricted to high mountain areas. Porous rocks filled with water may be gradually disrupted by frost action. This is well seen on the face of an old chalk quarry. Part of the face is blackened by weathering, but throughout the winter fresh white patches may be seen where frost has scaled off the surface layers. One of the greatest advantages of ploughing in the autumn in a country such as England is that during the winter the large clods of earth are broken up by frost action, allowing air to penetrate into the soil and rendering it more tractable for cultivation in the spring. On the other hand, the autumn sowing of grain is rendered impossible in lands with severe frost, for not only is the surface soil broken up but the seeds and little plants may be lifted right out of the ground by frost and their tender roots torn to pieces. The shedding of their thin-skinned leaves by deciduous trees is a protection against their disruption by frost, whilst many plants with large watery stems and leaves (*e.g.* the familiar garden marrow and the nasturtium) are killed by the first touch of frost which thus secures the retention of decaying vegetable matter in the soil.

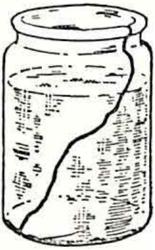
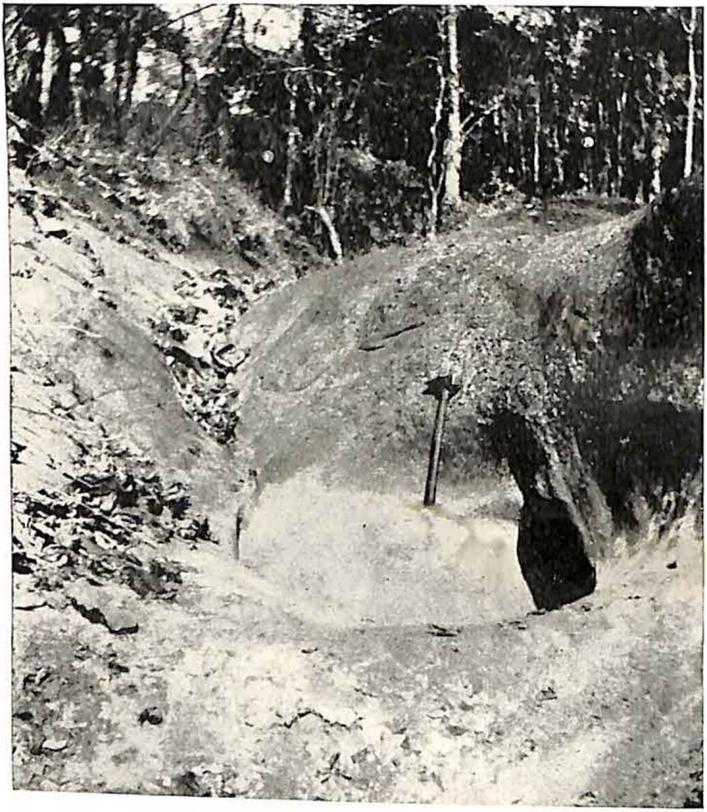


FIG. 21. A Jar Split by the Freezing of the Water it contained

Action of Running Water.—The action of the sun, wind, rain, and frost really constitutes "*atmospheric weathering*." As soon as the raindrops run together to form a tiny stream or rivulet, denudation of another type starts. As with rain water, the action of a river in its work of erosion and denudation is partly mechanical, partly chemical. The mechanical action is universal, the chemical more limited. The force of the moving water itself is sufficient to wear away its banks where these consist of soft material and to cause further destruction by undercutting. Large fragments of rock are rolled along the bed and pounded against one another to form rounded pebbles and sand, whilst the bed of the river itself is eroded by the passage of these fragments. The smaller particles are carried along in the body of the water itself (in *suspension*) and the water thus armed with sharp fragments of sand has its power of erosion greatly increased



[*Photo : L. D. Stamp*

FIG. 22. A Small Roadside Pothole, Burma

Photo taken in the Dry Season.

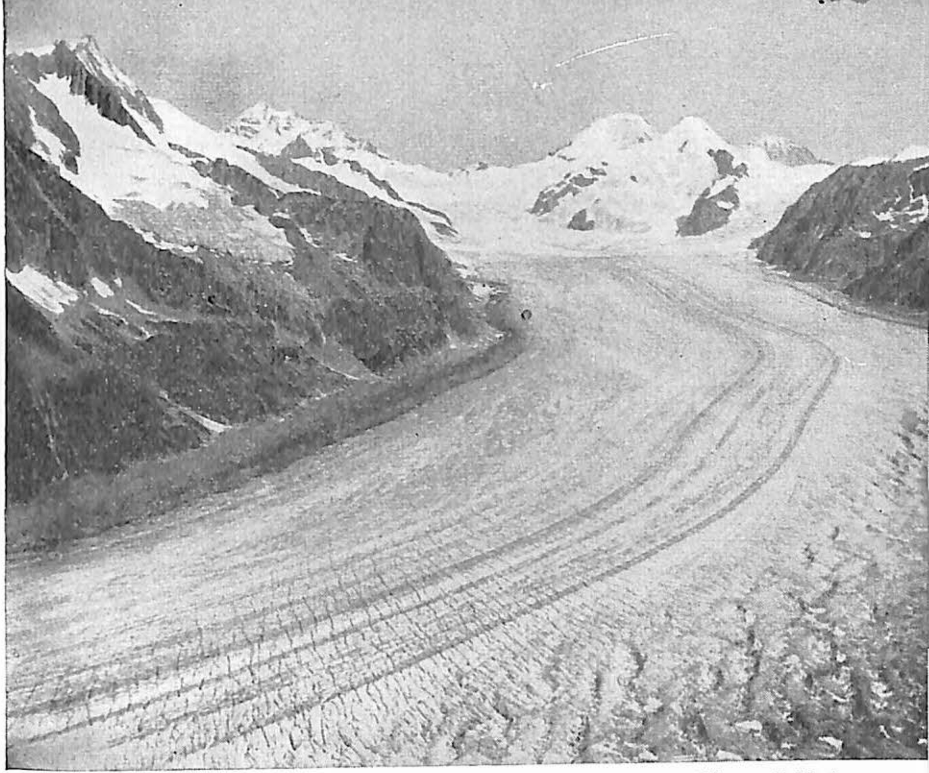
(compare wind). The fragments of sand are thrown against one another and gradually worn down, but below a certain size they are entirely buoyed up by the water which thus acts as a cushion between them. Thus the smallest particles remain angular (contrast wind-blown sand, Fig. 15).

The erosive action of running water increases greatly with its velocity. Actually the increase is roughly equivalent to the square of the velocity, so that the erosive power of a stream flowing at 8 miles per hour is four times that at 4 miles per hour or 16 times that at 2 miles per hour. Thus the bulk of the work of erosion by rivers is done in times of flood—notably in tropical countries subject to periodic rains.

The work of a river as a whole will be considered later, but it may be noted that the water, in swinging from side to side, gradually widens the valley and at the same time cuts downwards. When a swift stream is in flood there is a tendency for stones to be whirled round and round (especially at the foot of rapids or a waterfall) and for a " pothole " circular in shape to be cut out even in the hardest rock.

The Action of Moving Ice.—In high latitudes and at high altitudes, where the temperature of the warmest month is near or below freezing, precipitation is in the form of snow, and glaciers replace rivers. The action of snow is, as a whole, protective rather than erosive ; the minute hexagonal crystals of ice which make up snowflakes interlock so as to include a large amount of air. Air being a bad conductor of heat, the snow acts as a blanket (a woollen blanket being warm for the same reason—occluded air) and limits the disruptive action of frost on the rocks which it covers. But with the further fall of snow the lower layers are compressed as névé or firn, and where the accumulation is on a slope the mass begins to move. A sudden slide of a mass of partly compressed snow constitutes an *avalanche* which may cause considerable destruction. But where the accumulation of snow is at the head of a valley, the pressure of newly fallen snow from above gradually propels the mass of firn—now consolidated into ice—down the valley as a glacier. Just as with a river, friction along the sides and bottom of the glacier retards it, and the greatest rate of flow is found in the centre of the surface. This can be proved by driving in a line of stakes across the surface. Ice cannot swing from side to side as does the water of a river, and so valleys carved out by glaciers tend to be straight and without spurs as well as U-shaped in section. Where a glacier is forced to round a curve in its valley, or where the valley floor suddenly steepens (compare rapids in the case of a river) the ice cracks and great *crevasses* are formed. The erosive power of ice alone (compare water of a river) is limited, but masses of stone (such as those which may fall down crevasses) become frozen into the glacier, which then acts as a powerful rasp, eroding its bed and grinding the stones themselves to fragments. The hardest rocks may only be scratched (*glacial striæ*), but softer rocks are literally scooped out. Thus a glacier has the power (possessed scarcely at all by rivers) of scooping out hollows in the surface of the valley over which it passes. If later, for various reasons, the glacier melts, these will become occupied by lakes.

A glacier occupying a previously existing river valley cuts away the spurs and so the lateral valleys, when the ice disappears, become " hanging valleys " with a sharp drop between their mouths and the deepened floor of the glaciated valley. Where a glacier meets an obstacle such as a hard rock in its path it smooths the obstacle except on the leeward side. So smoothed rocks or roches moutonnées have a characteristic form, and large obstacles



[*Photo : E. N. A.*

FIG. 23. General View of the Aletsch Glacier, Alps
Showing Lateral and Medial Moraines

exhibit "crag and tail"—there is a steep crag or cliff facing the ice, from the base of which all loose material has been removed, and a long "tail" where such loose material has been protected.

In addition to valley glaciers, large areas of land in arctic and antarctic regions may be completely covered by an ice-cap, ice-sheet, or ice-field. In the case of Greenland the ice-cap is many thousands of feet thick. The whole mass moves very slowly outwards from the centre of accumulation, giving rise to tongues of ice round its margins.

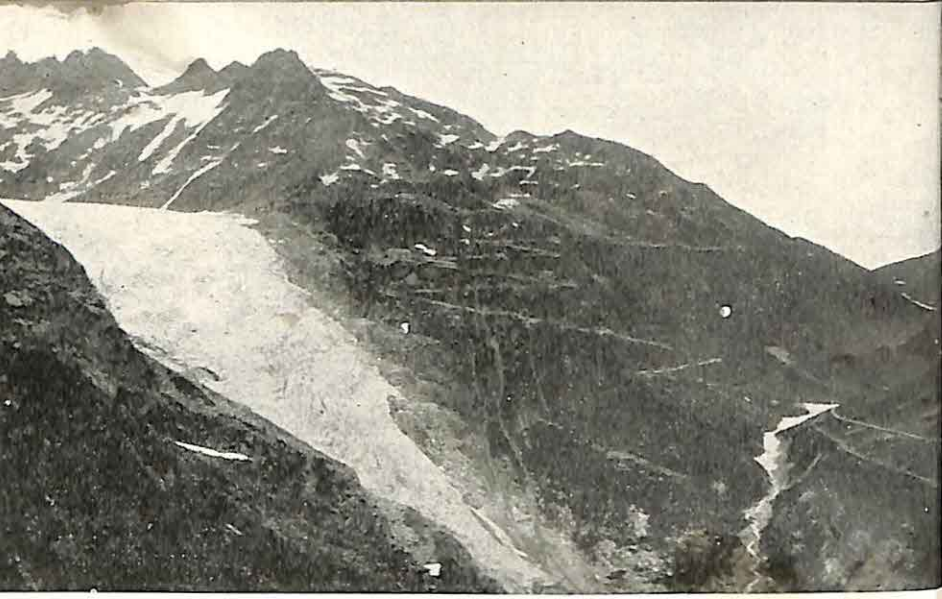
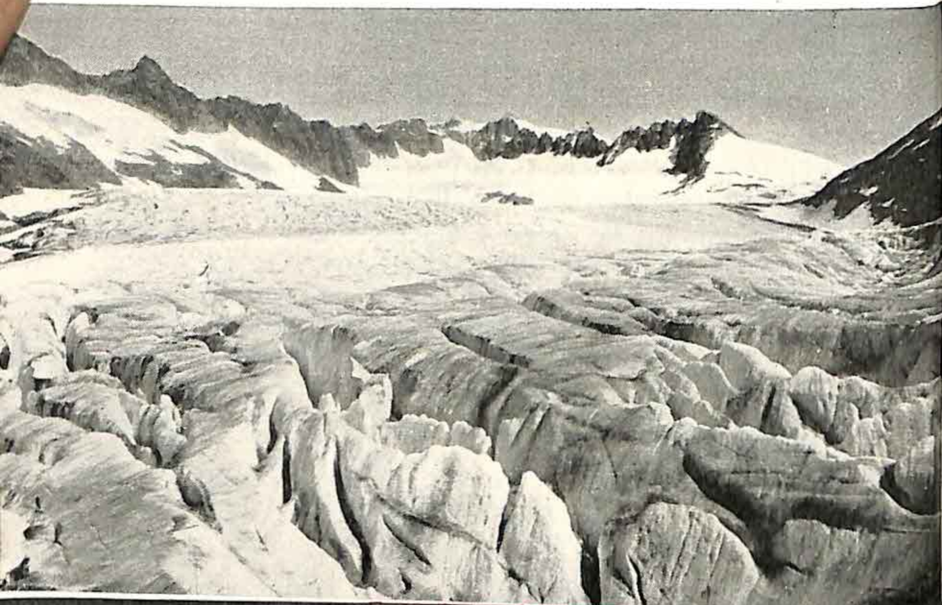


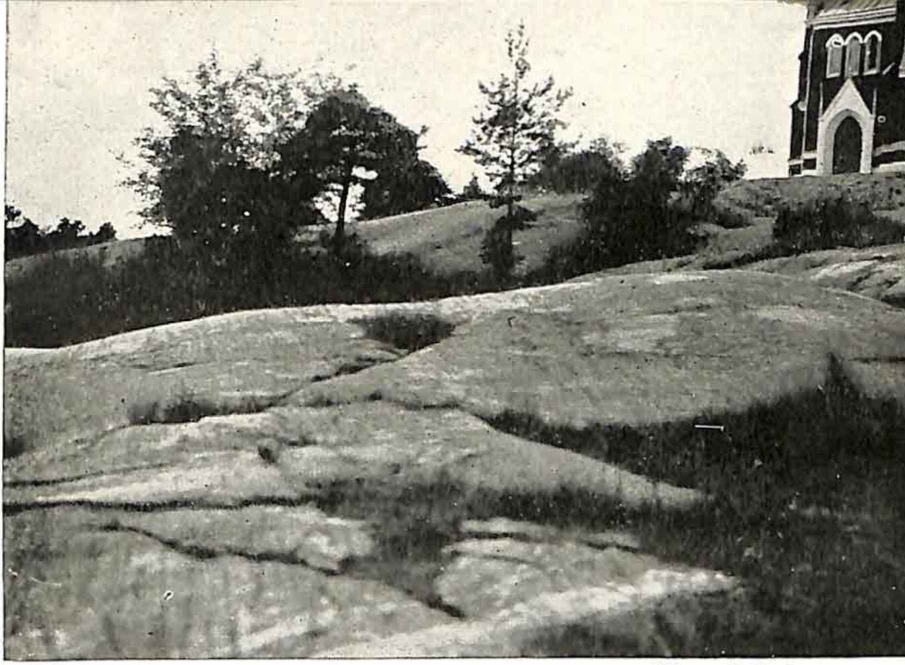
Photo : Courtesy of George J. Miller

FIG. 24.—General View of the Rhone Glacier—the Source of the River Rhone

FIG. 25. Details of the Rhone Glacier, showing the Crevasses which are formed where there is a change of slope (shown in the above general View).

[*Photo : Courtesy of George J. Miller*



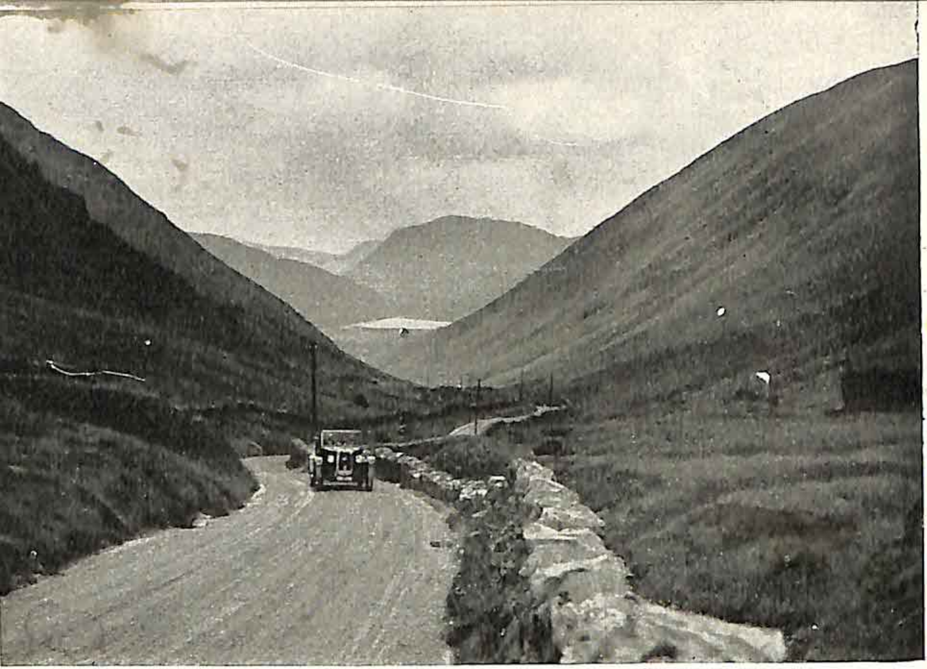


[*Photo : L. D. Stamp*

FIG. 26. Striated Rocks in Glaciated Country, Hango, Finland

In other cases, as in Alaska, many valley glaciers may join together on lower ground to form a continuous sheet of ice, or piedmont glacier. The surface under such ice sheets is a hummocky one of smooth outlines, all loose material having been removed and only the hard rocks left.

In parts of the world subject to considerable variations of temperature between summer and winter, the rivers of summer become frozen over in winter. When the spring comes the ice melts. Great angular blocks of ice may be swept downstream by the floods which result, and such moving masses of ice have a marked power of erosion.



[Photo : L. D. Stamp

FIG. 27. A U-Shaped Glaciated Valley
English Lake District

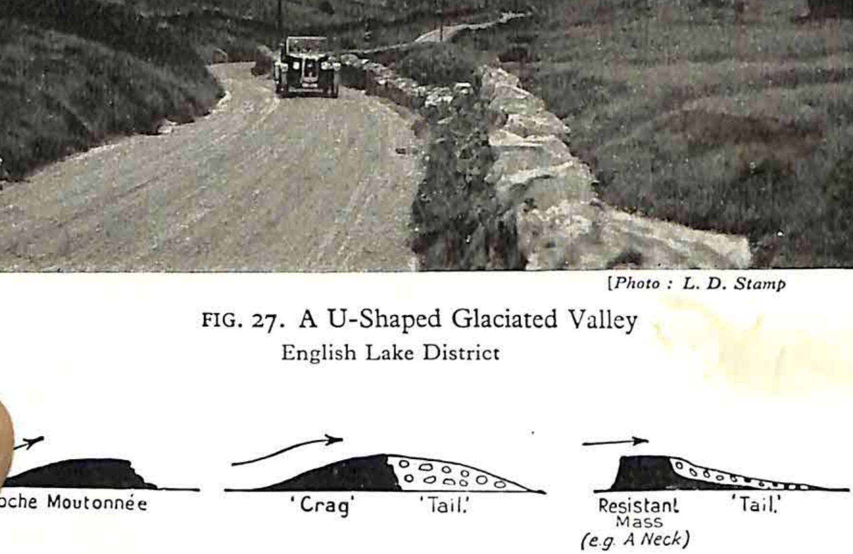
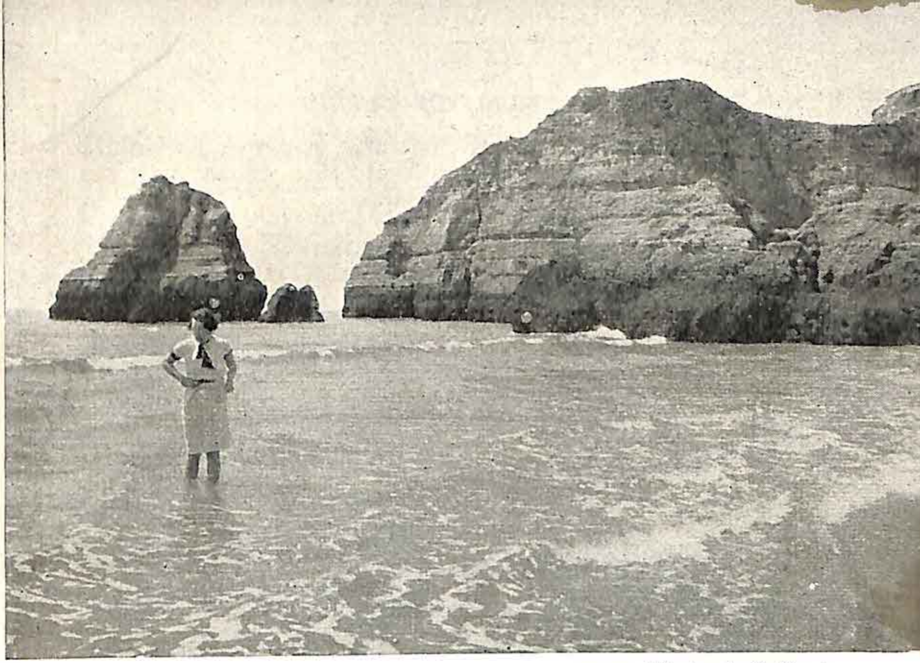


FIG. 28. Accumulation of a Tail of Boulder Clay in Lee of a Rock Crag

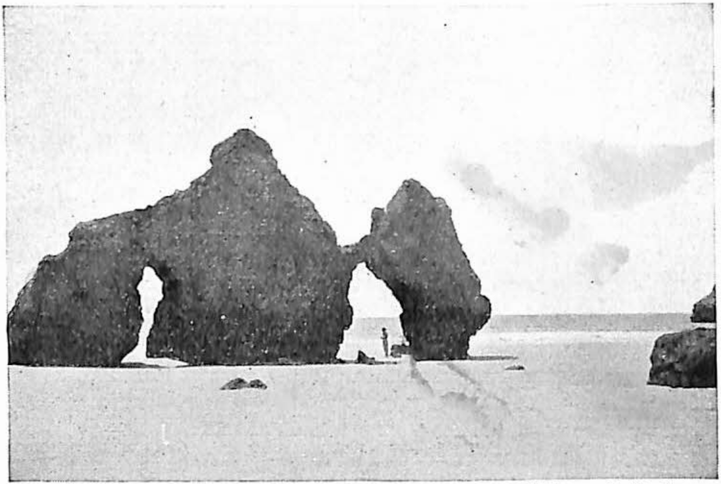
The Action of the Sea.—The action of the sea, powerful as it is, is limited to its margins, where there is a constant struggle between land and sea. At great depths, the waters of the sea are undisturbed except for gentle ascending or descending currents due to temperature and salinity changes, and so erosion is absent. The greatest waves of the



[*Photo : L. D. Stamp*

FIG. 29. A Stack, Southern Coast of Portugal

severest storms rarely disturb the waters at a depth of more than a hundred feet. But round the margins the erosive power is very great. The waters are rarely still and the breaking of the waves on the shore is capable of effecting erosion by hydraulic force alone. This is greatly increased in times of storm and is well seen on high rocky cliffs where water rushes with great force into narrow rock crevices. But the water is almost invariably armed with masses of rock and stone, and its erosive power greatly increased. The masses of rock are smoothed, the stones broken and rounded, and sand produced. As with the case of river sand, the smallest particles are buoyed up by the water and tend to remain angular. The sea soon locates lines of weakness in rocks—it excavates along such lines to form *caves* or to isolate masses of rock from the main cliffs as *stacks*. Where outcrops of soft rocks reach the coast, *bays* and *gulfs* are eaten out, separated by headlands of harder or more resistant rocks. Where the shore line is formed by high cliffs, the action of the sea is increased by its undercutting action and the consequent collapse of the cliff above.



[*Photo : L. D. Stamp*

FIG. 30. Stacks on a Limestone Coast, showing the combined effect of Solution of Limestone by substantial denudation and the action of the Sea (Algarve, Portugal)

Because wave action is limited in depth the general result is for the sea to form a platform or shelf surrounding the land at a depth of 60 to 600 feet. Slow movements of elevation and depression (see below, p. 94) affect the level of these platforms, so that parts may be at much greater depth (continental platform, around the continents) whereas parts may be raised above sea-level (raised beaches).

The sea has also an erosive action due to the existence of currents, but ocean currents, however important their effects on climate, vegetable, and animal life, have very limited erosive powers. Much more important is the erosive action due to the tides, an action most marked in estuaries. Very powerful currents are set up which sweep debris seawards (*tidal scour*). Not infrequently use is made of this action in harbours where the sea is allowed to fill a basin at high tide, the water in which is then shut off, to be released at the time of low tide, when it naturally rushes out with considerable force and helps to clear the harbour of accumulated sand and mud.

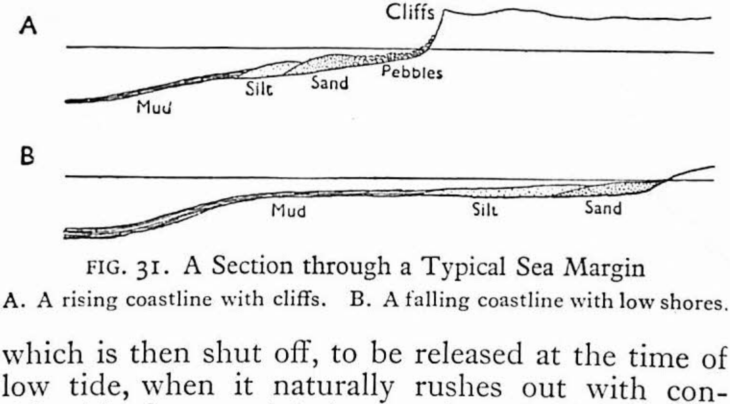


FIG. 31. A Section through a Typical Sea Margin
A. A rising coastline with cliffs. B. A falling coastline with low shores.

The Action of Plants, Animals, and Man.—Whilst the general result of a covering of vegetation is to protect the surface from the destructive action of sun, wind, rain, and frost, plants have important effects of their own. There is first the disruptive action of roots (and sometimes of stems), well seen in the case of ivy on old walls, where growing roots are able to burst asunder great masses of masonry.

Even the humbler plants are seen to have unexpected power in this way—as when paving stones are lifted by the growth of fungi. This action may be described as a mechanical action, and it is undoubtedly important in the formation of soil. But there is also a chemical action. When water is absorbed through root hairs, a certain amount of cell sap passes out in the opposite direction (the process of *osmosis*) and this cell sap is a weak acid, capable of dissolving certain rocks. If a piece of polished marble is covered with a little fine sand

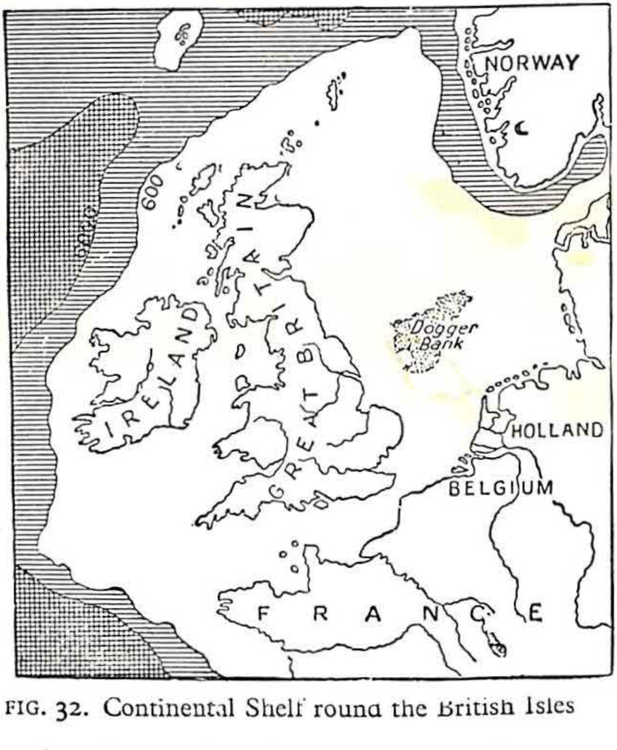
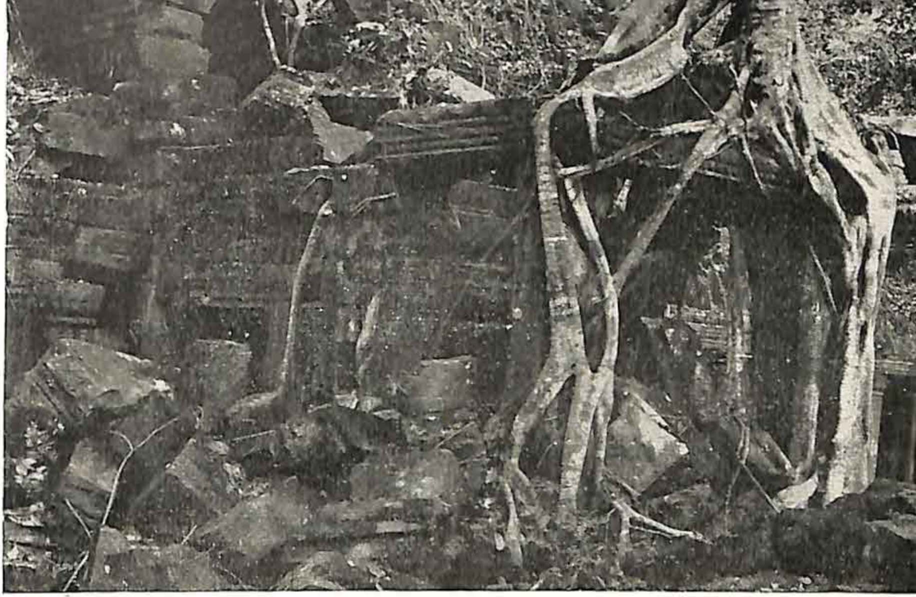


FIG. 32. Continental Shelf round the British Isles



[Photo : L. D. Stamp

FIG. 33. The Entrance Gateway to one of the Temples of Ankor (French Indo-China) Disrupted by Vegetation

(which can be kept moist) and seeds (such as mustard and cress) allowed to germinate, the roots of the seedlings will etch little channels in the marble.

Animals have both a direct and indirect action as agents of denudation. The larger animals by their burrows cause the collapse of cliffs, river banks, and the spread of desert-like conditions by the destruction of vegetation ; good examples are afforded by rabbit " warrens," the burrows of muskrat on river banks, and the " caves " of such birds as sand martins. On the sea shore such burrowing molluscs as *Pholas* play a considerable part, and amongst the innumerable smaller agents of destruction ants are especially widespread. The action of earthworms in promoting the formation of soil is well known.

Man is capable both of imitating and of greatly

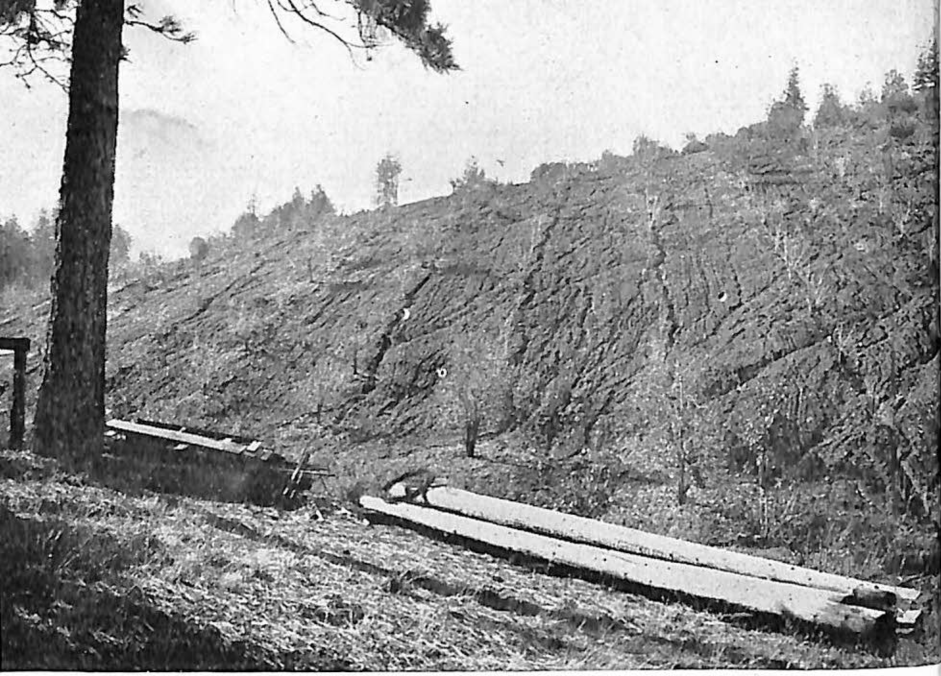
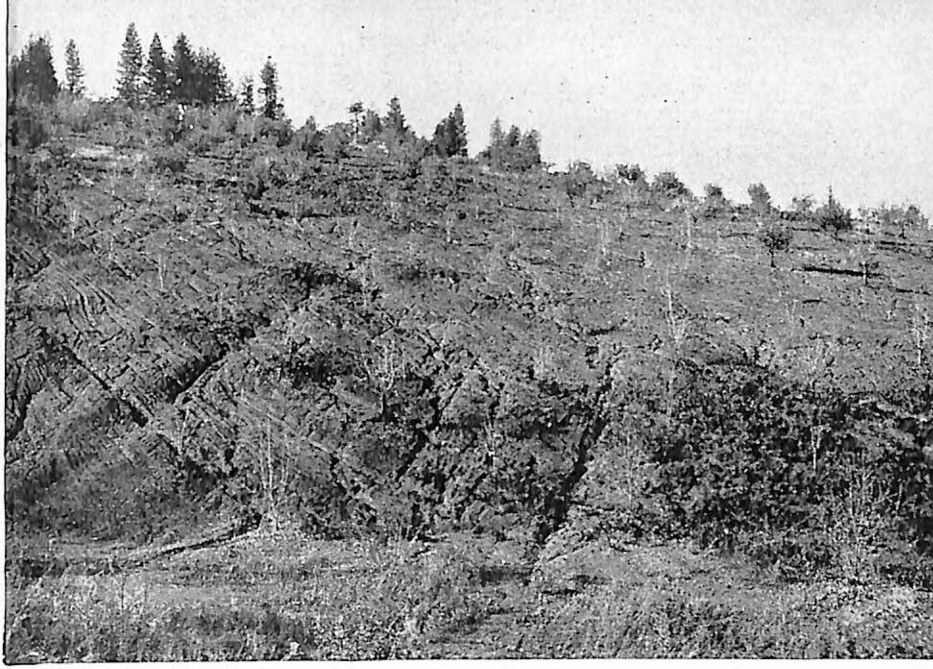
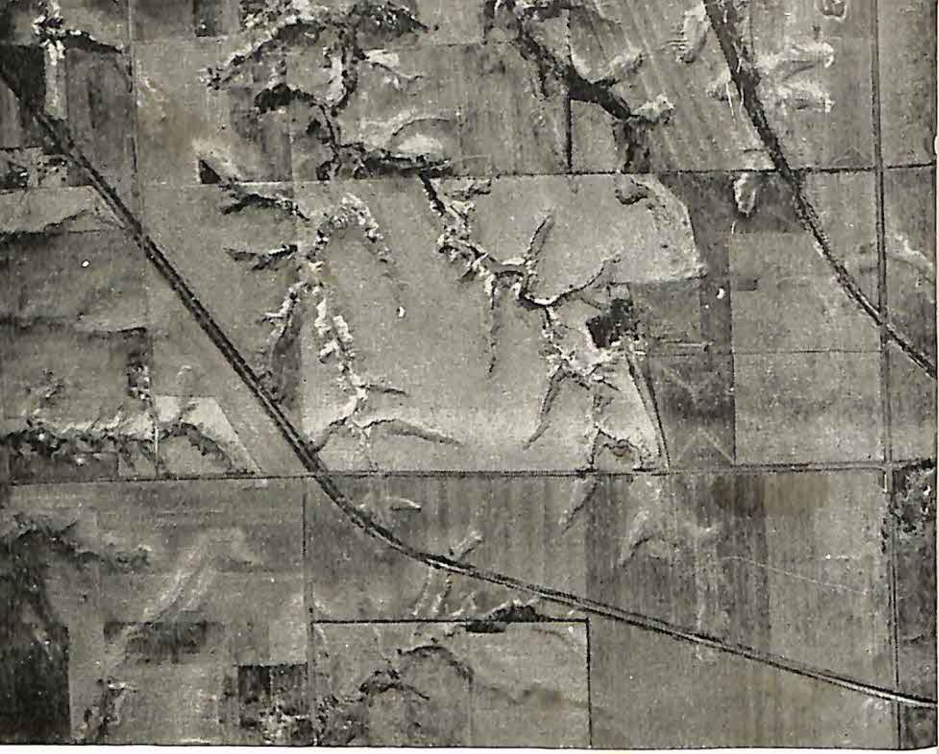


FIG. 34. Erosion in a Pear Orchard in California, resulting
October



[*Photo : A. E. Wieslander, courtesy California Station, U.S. Forest Service*

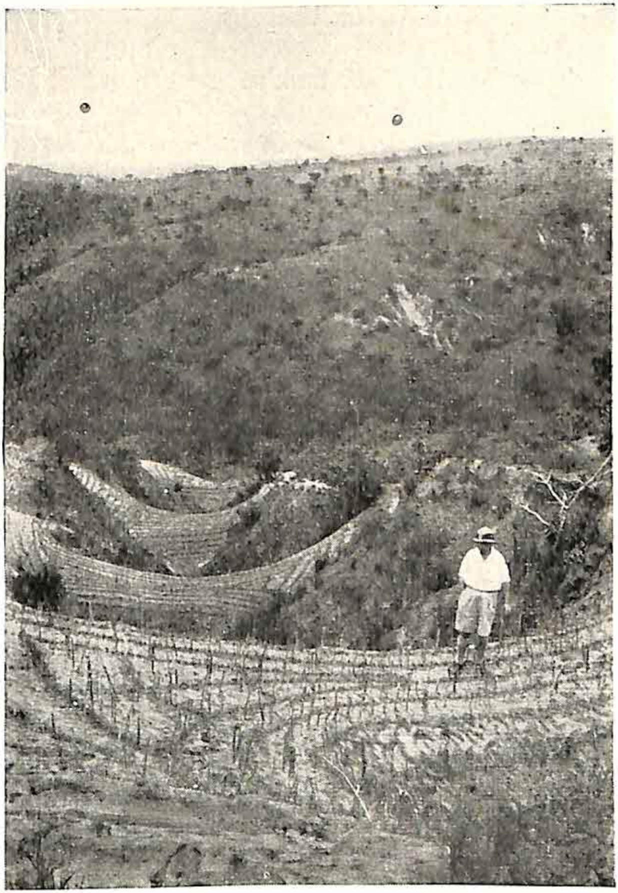
from a single storm during which 4 to 5 inches of rain fell,
29–31, 1933



[*Photo : U.S. Govt.*

FIG. 35. Aerial View of Soil Erosion and the Development of a Drainage System following on Cultivation

accentuating the natural destructive processes of nature. The making of quarries, mines, and cuttings may be described as the direct work of man as a geological agent, whilst the indirect work resulting from the exposing of great tracts, formerly grassland or forest, to the destructive action of wind, rain, and running water is vastly greater.



[*Photo : L. D. Stamp*

FIG. 36. An attempt by man to stop the Erosion which he himself has caused by Clearing the Forest

Dam planted with grass and trees across a gulley, Udi Plateau, Nigeria.

CHAPTER IV

TRANSPORTATION AND DEPOSITION

General.—In the last section we considered those agents which are responsible for the breaking down or wearing away of the earth's crust. What happens to the material which is thus removed ? The sum total remains the same, so that actually it is simply transported or moved from one part of the earth's crust to another and there redeposited. Most of the agents which are responsible for the processes of denudation also act as agents of transportation and deposition, and we shall now consider their importance in these aspects.

The Action of Wind.—The transporting action of wind is well known. In dry periods clouds of dust are blown about even in city streets and the action is naturally most marked when the wind is strong or develops strong gusts. In some respects the transporting action of wind resembles that of a river—the larger particles (sand) which cannot be raised are rolled along the ground and the smaller particles (dust) are carried in suspension in the air. The transporting action of wind naturally increases where there is a large tract of sand or dust which it can move, and its influence tends to be cumulative. Thus where there are small tracts of sand or dust, small dust storms occur, but where man has laid bare by cultivation huge areas of fine dusty soil, the dust storms become of enormous proportions and in the case of the middle western states of America, and parts of southernmost Saskatchewan and Alberta,

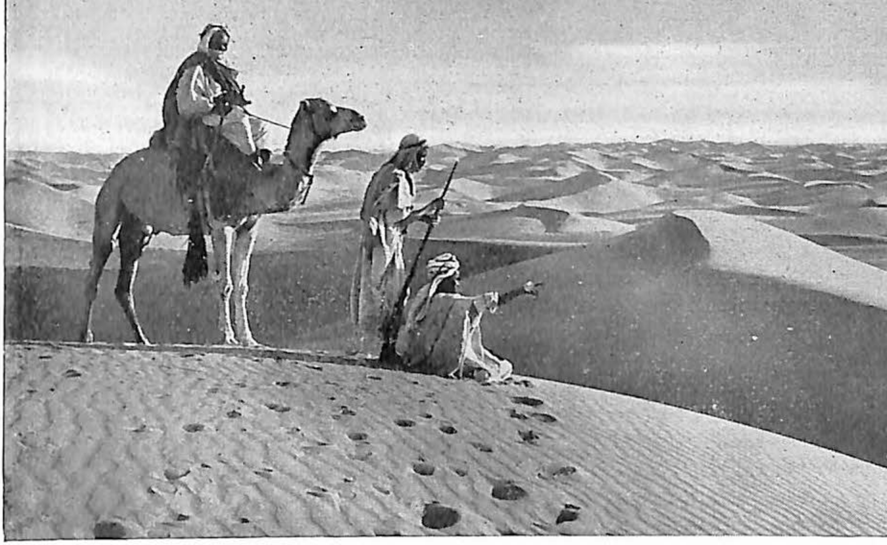


FIG. 37. Sand Dunes in the Sahara

the soil has been virtually removed from over huge areas and redeposited elsewhere. The effect is to cause, apparently, an increase in desert conditions, and the "encroaching of the Sahara" is causing great concern to the countries by which it is bordered in Africa (see below, Figs. 41 and 42).

Sand blown along a surface tends to form a series of waves like the ripples on a sea shore. There are both minor waves (as shown in the foreground of Fig. 37) and major waves or sand dunes. A sand dune generally originates with a small obstruction—a rock or a tuft of grass or a bush—on the surface against which sand is piled up. Then the dune grows in such a way that in cross-section (*i.e.* a section parallel to the direction of the wind) it has a long gentle slope *facing* the wind, and up which the particles of sand are blown and a steep slope away from the wind down which the grains tumble (as shown in the diagram). Looked at in plan the typical dune is crescent shaped, for the wind blows the grains round the sides of the dune.

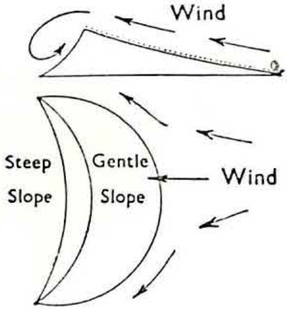
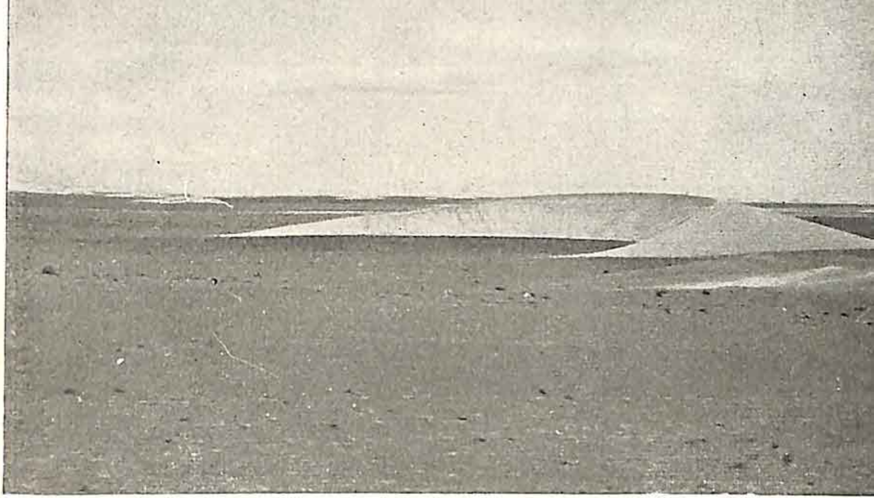


FIG. 38. Diagrams showing the Formation of Sand Dunes

In regions of constant wind the dunes move steadily forward, often only a few feet a year, and it is only when "fixed" by vegetation that movement ceases. Cases are common round the British Isles where dunes moving inwards from a sandy coast gradually overwhelm forests.

In the case of dust storms there is, in most dry regions of the world, a prevalence of small whirling storms which are due to local differences in heating and which tend to whirl across the country in a narrow path in the afternoon. In the case of the greater dust storms, dust is lifted high into the air and may completely obscure the sky for several hours. Eventually the dust settles as a fine impalpable layer of powder evenly spread over the surface. Such is the fine dust deposited by the Harmattan or dry wind which blows southwards from the Sahara over the countries of the West Coast of Africa. Cold outblowing winds from the centre of Asia have resulted in a mantle of dust, known as *loess*, being deposited over huge areas of North China. Indeed loess deposits occur over enormous areas of North America, Europe, and Asia, and represent deposits left by outblowing winds from the old ice-sheets. Sometimes the deposits have been partly re-sorted by water ("brickearths"



[*Photo : L. D. Stamp*

FIG. 39. Typical Crescent-shaped Sand Dunes of White Sand on the Hard Surface of the Desert of Southern Peru (near Arequipa)

as in southern England and the "limon" of northern France), but typical windborne loess is characteristically without notable stratification, and is banked up against the hill-sides as shown in the diagram. Loess has often a curious vertical jointing and appears to have little vertical tubes running through it. These may be due to the remains of the roots of grass and other vegetation which grew as the loess accumulated.

In the great American dust storms, the soil which

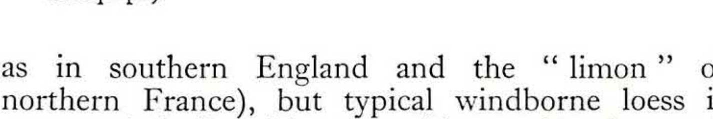
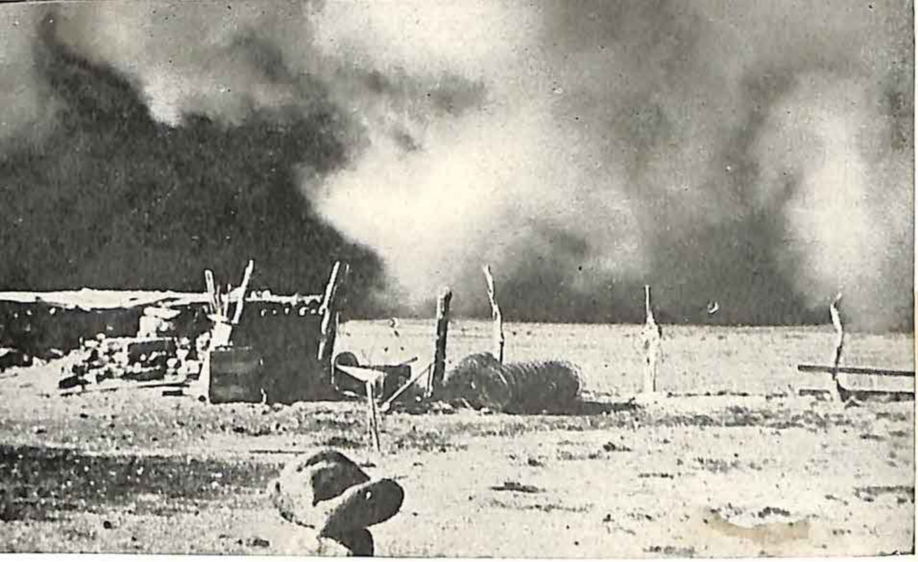


FIG. 40. Diagram Showing the Mode of Deposition of Loess in Northern China

This windborne deposit is not laid down in level layers as with waterborne deposits, but is banked up against the mountain ranges.

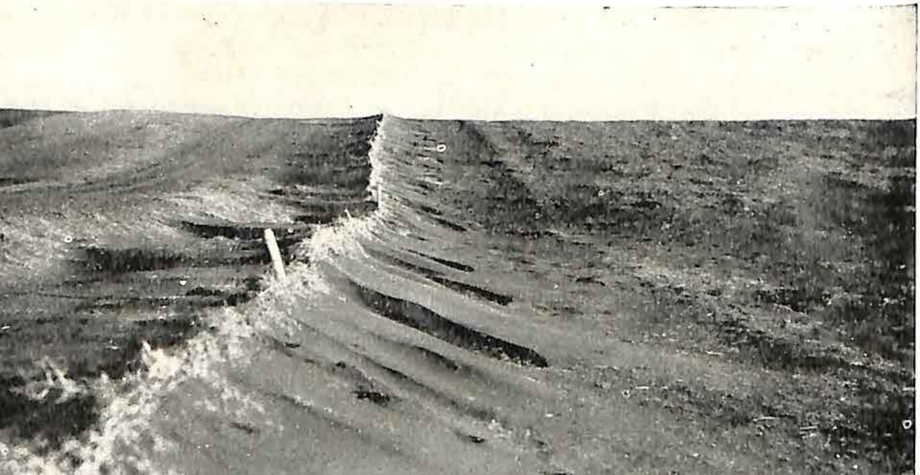


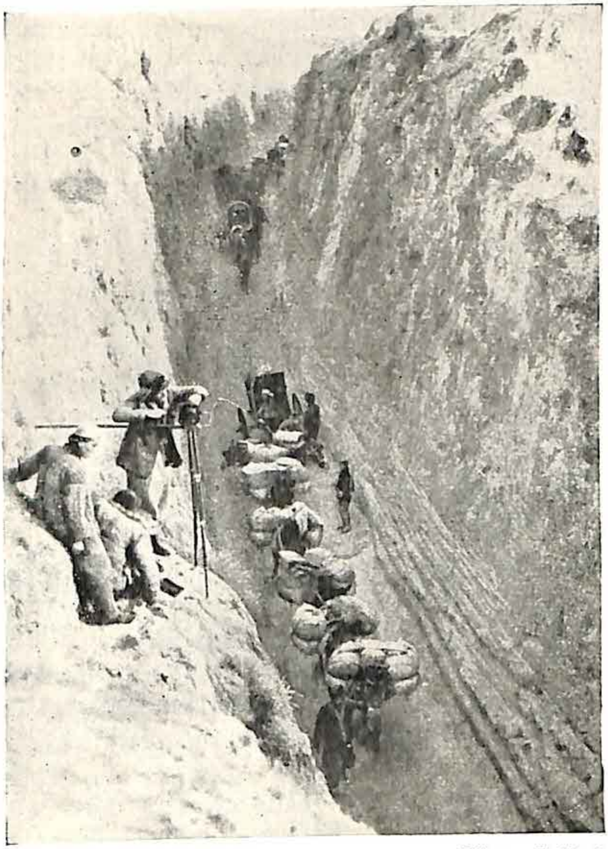
[Photo : E. N. A.

FIG. 41. A Dust Storm in the United States

FIG. 42. Deposition of Soil after a Dust Storm in South Dakota

Photo : U.S. Govt.





[Photo . E. N. A.

FIG. 43. A Road through the Loess of Northern China

is swept from one area is piled irregularly against any obstacles which present themselves in another.

It will be seen that *æolian deposits* which have been laid down by wind on dry land may be distinguished by (*a*) the inclusion of minute grains perfectly rounded and polished (Fig. 15); (*b*) the absence of regular bedding and the frequent presence of dune structure and, in the case of loess, of vertical jointing. Æolian deposits are often banked up against hill-sides, and there is a frequent tendency for the deposits to be reddish in colour and to be saline (indicating deposition under desert conditions with no rain to dissolve the salts).

The Action of Running Water.—The course of the normal river may be divided into three parts :—

(*a*) The upper course, where its main work is that of erosion—the wearing away of the rocks.
(*b*) The middle course, where its main work is transportation—the carrying of the material from one region to another.
(*c*) The lower course, where its main work is deposition—the laying down of its burden in new positions.

It has already been pointed out that in the work of transportation the coarser stones, gravel, and sand are rolled along the stream bed whilst the finer sand, silt and mud are carried along in suspension. It has also been pointed out that the ability of the river to move material varies according to the square of the velocity and so changes greatly from one season to another. Thus erosion and deposition often go on side by side; a river is often eroding a concave bank while a sandbank is being formed on the opposite bank. Fig. 44 shows how this results from the swing from side to side of the main current of water. Thus deposition is often of a temporary nature and a sandbank formed during a period of slow movement may be swept away at a later stage With many of the larger rivers the current becomes so slow that the river is no longer able to carry its burden of suspended mud, and this is dropped on the river bed so that eventually the river chokes its own bed and seeks a course elsewhere. Man is compelled to embank the river to prevent this happening, and so in Northern Italy (the Plain of the Po) and North China (the plain of the Hwang Ho) the rivers now flow above the general surface of the land. The embankments are known as levées in America.

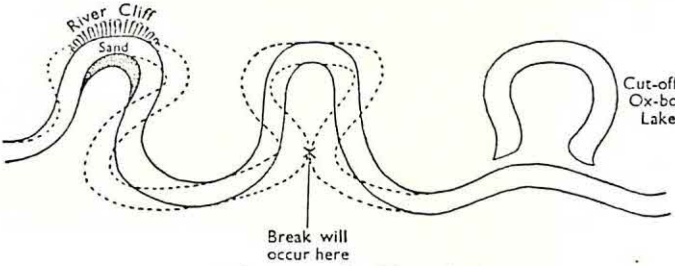


FIG. 44. Diagram of a Meandering River
The meanders tend also to move gradually down-stream.

The burden of fine sand, silt and mud which a river deposits when it floods or when it reaches the sea or a lake is known by the general name of *alluvium*. The level land on either side of a stream which is normally or commonly flooded is its *flood plain*, consequently flood plains are built up of alluvium. Where a swift river enters suddenly the comparatively tranquil waters of a lake, it drops its load of sand somewhat abruptly—rather like a man tipping a load out of a wheelbarrow—and the next load is of necessity deposited further out into the lake, and the delta so formed grows gradually outwards. A section through such a delta would appear somewhat as in Fig. 45. Thus the deposit at (*a*) would be the oldest and at (*b*) the youngest.

Such irregular deposition takes place also under the influence of currents (as in sandbanks) and is so known as *current-bedding* or *false-bedding*.

A mountain stream suddenly reaching a plain finds its velocity checked and much of the material it carries is deposited as an "*alluvial fan*" of coarse sand and stones. Often such fans are largely scree material only slightly sorted and the streams themselves flow only after a storm.

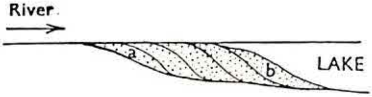


FIG. 45. Diagrammatic Section through a Delta in a Lake

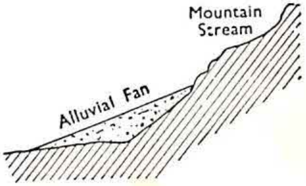


FIG. 46. Diagram of an Alluvial Fan

Where a river enters the sea with its burden of sand and mud the whole may be swept away by swift currents. But where the sea is quiet, the silt and mud are spread over the sea-floor as a thin layer. The same happens when a comparatively large, slow-flowing river enters a lake. This is shown diagrammatically in Fig. 47. Here it is clear that the layers at (*a*)—at the bottom—are the oldest, and the layers at (*b*)—at the top—are the youngest. In any extensive series of deposits this

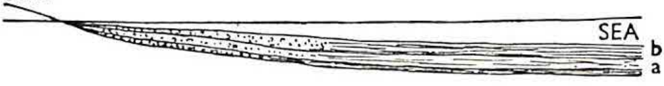
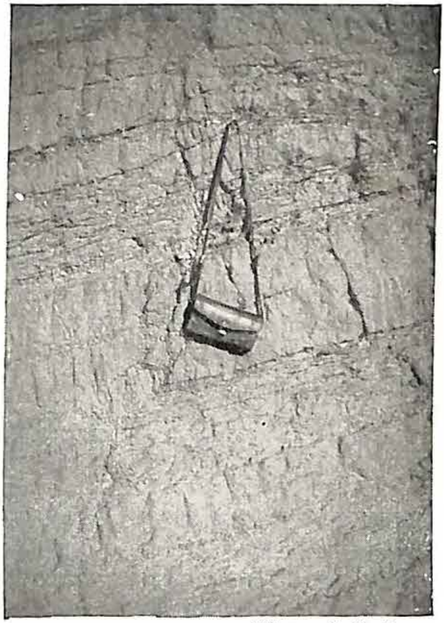


FIG. 47. Section through Deposits in a Lake or Sea



[*Photo : L. D. Stamp*

FIG. 48. Banded Estuarine Deposits (Peguan of Burma)

is the usual rule—the youngest deposits at the top—and is known as the *law of superposition.*

Rivers thus tend to drop their load when they enter the sea and the process is helped by the presence of salts in the water which coagulate the clay or fine particles, and cause them to sink more rapidly. Gradually the river pushes its delta out to sea and the water finds its way seawards through a number of channels or distributaries. The deposits formed in estuaries, where there is a mixing of fresh and salt water, are estuarine or brackish water deposits; not infrequently they are finely banded—a thin layer of sand is deposited in the high-water or flood season of the river, a thin layer of mud during the quiet or low-water season.

Deposits in fresh-water lakes differ in several ways from the marine deposits described below. The clays are often reddish, and mottled reddish-grey, grey, or white *pipe-clays* may occur. The sands deposited in shallow water are often false bedded and associated with peat beds. In clean lakes (*i.e.* away from mud brought in by rivers) fresh-water limestones may develop.

The Action of Moving Ice.—Glaciers transport material in several ways. Blocks broken off by ice action fall on to the sides of the glacier and form *lateral moraines* which are carried slowly onwards; when two glaciers join the two lateral moraines naturally join up and form *medial moraines*. Those blocks which fall down crevasses and are such powerful aids to its erosive powers are also carried forward as *ground moraines*, and are usually distinguished by their very striated surfaces. In high latitudes—that is, near the Arctic or Antarctic regions—the glaciers reach sea level and great masses break off, together with their burden of moraines, and float away as icebergs. Eventually the bergs melt and their loads are dropped on to the sea floor. In warmer lands the valley glaciers from the mountains do not reach sea-level, but may melt long before they ever reach lower ground. Deposit of the material therefore takes place. As the glacier shrinks laterally some large boulders from the lateral moraines may be left precariously perched on the valley sides (*perched blocks*). At the melting lower end of the glacier the icy cold melt-water usually issues from an ice cave and carries with it the smaller stones and sand. But the larger boulders are dropped where the ice melts and gradually an irregular mass is built up known as a terminal moraine. The boulders distributed by ice action are often carried very far from their original source, and when dropped they are very different from the rocks of the surrounding country. Hence they are known as erratics (Latin, *erro*=I wander).

During the Great Ice Age (see p. 212) which occurred comparatively recently in the geological history of the earth, great ice sheets covered much of North America, Europe (including Britain as far south as the Thames) and Asia. So the deposits left behind by these ice-sheets are of special importance and interest. The chief deposits may be grouped as follows :

(1) *Terminal Moraines*.—These consist mainly of large stones and form ridges often of considerable height which mark stages in the retreat of the ice-sheets. The long east–west ridges of Long Island, New York, are well-known examples from North America ; and the great ridges running across Germany, roughly from east to west, originated in the same way. A smaller example is the ridge on which the British cathedral city of York is built.

(2) *Outwash Fans of Sand and Gravel*.—These are due to the great stream of melting water in front of the ice sheets carrying masses of stones, sand, etc., and spreading it fanwise over great tracts of country. Such tracts are now often tracts of poor light soils.

(3) *Till* or *Boulder Clay*.—When the main mass of ice melts it leaves behind a very irregular mass of boulders of all sizes embedded in much finer material which consists mainly of ground-up rock

débris. This may be ground up so fine as to form clay or it may be coarser and more like sand in character. But the material is not sorted as in the case of river deposits, and does not as a rule show bedding or stratification. *Drumlins* are smooth, rounded hills of till, having the shape of upturned boats, and having their long axes parallel to the direction of ice movement.

(4) *Eskers and Kames.*—Eskers are long, fairly straight ridges of sand and gravel that may have been desposited by melt-water rivers flowing under the ice-sheet. Kames are irregular masses of sand and gravel that were probably deposited along the ice-margin by running water.

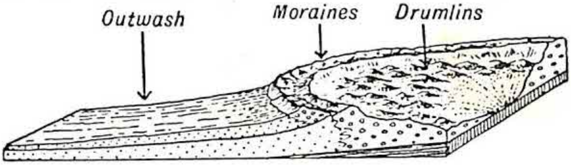
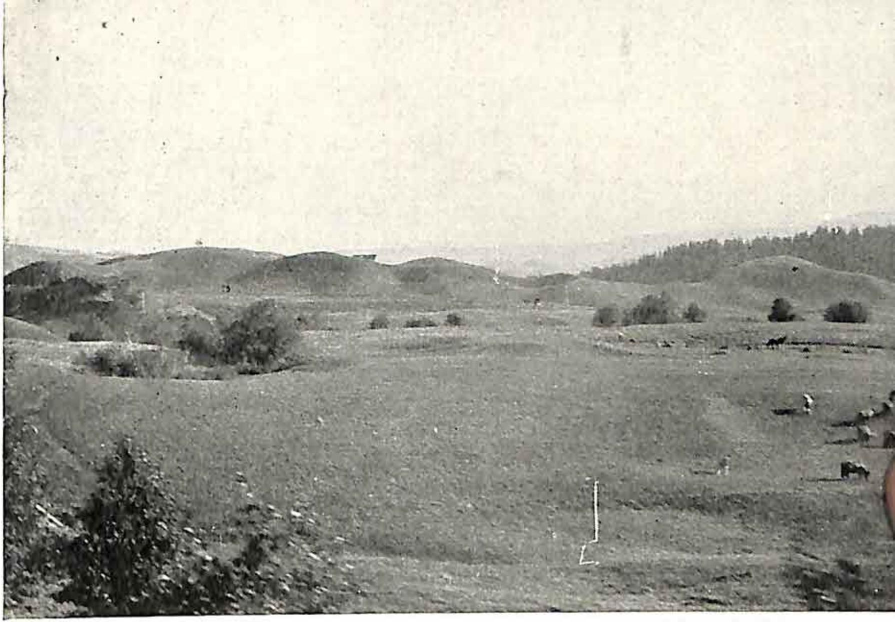


FIG. 49. Section Across the Glacial Deposits Associated with a Great Ice Sheet

(5) *Lake Deposits.*—The ice sheets often dammed up rivers and formed lakes in which a variety of lake deposits—often much like alluvium—are found. All stages in the drying up of the lakes are known. Great areas of Canada are underlain by clays deposited in very large ice-dammed lakes. Particularly in North Europe (across the North German plain) the rivers such as the Elbe and Oder could not reach their mouths covered by the ice and were compelled to flow parallel to the edge of the ice, cutting out valleys now occupied by alluvium and marshes, and known as *urstromtäler* (former river valleys).

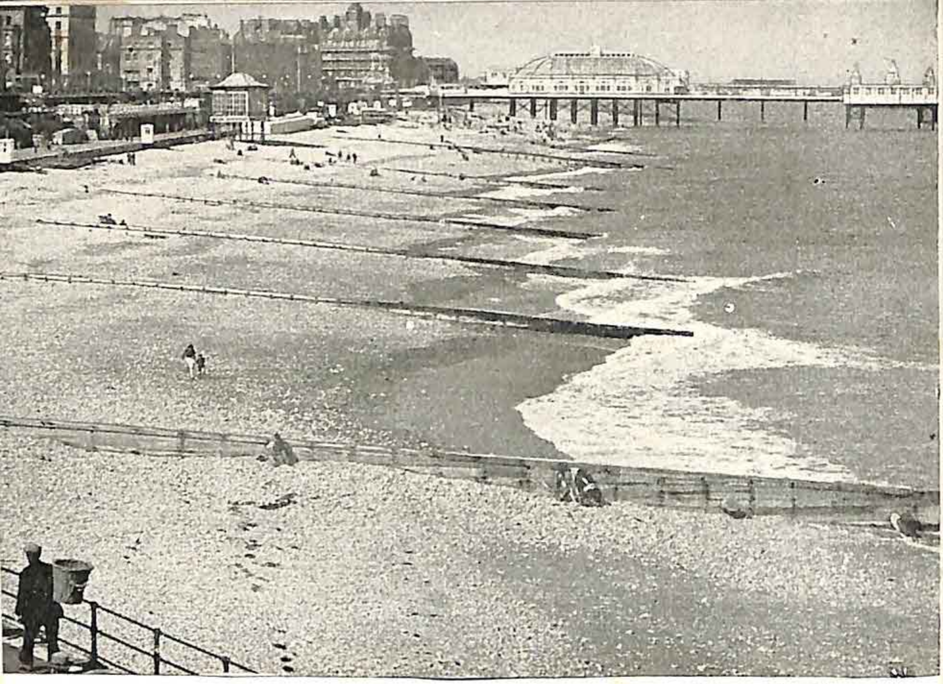


[Photo: L. D. Stamp

FIG. 50. Drumlins in a Norwegian Valley, formerly Glaciated (South of Trondheim)

(6) *Loess.*—The origin of loess, found outside the area actually covered by the ice sheets, has already been explained.

The Action of the Sea.—The sea transports material in two ways. There is first the drift along the coast of pebbles, sand, and mud, the direction of the drift depending on wind, waves, tides, and currents. It is usually in the same direction along any given stretch of coast and all round the shores of Britain, for example, *groins* are erected to prevent as far as possible or minimise the effects of the coastal drift. Interesting features are the formation of spits and bars of shingle and the filling of bays between rocky headlands with broad stretches of sand and shingle. Secondly, the sea sorts out the



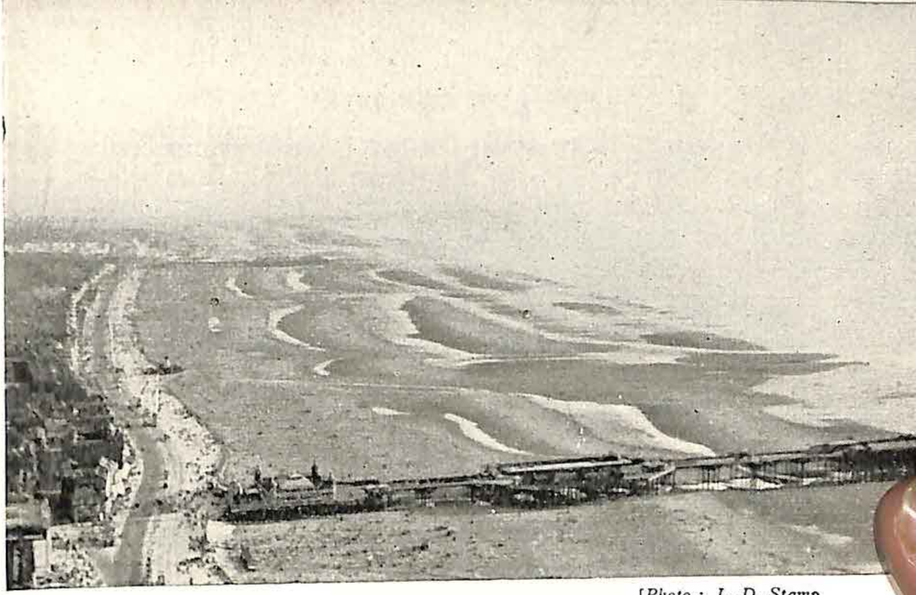
[*Photo : Fox Photos*

FIG. 51. Groins along the English Channel at Eastbourne. These are erected to minimise the Drift of Shingle along the coast, and it is clear from this picture which way the shingle has been drifting.

materials, leaving the coarser along the coast as shore deposits, carrying the sand below high water mark and some distance out, and carrying the mud further still before allowing it to settle in the quiet deep waters. In the wide open oceans it is too far for sediment derived from the land to reach.

Marine sediments likewise fall into different types. Perhaps the most important fundamental division is into:

(*a*) *Terrigenous deposits* or those derived from the wearing away of the land and which are found



[*Photo : L. D. Stamp*

FIG. 52. A Coast undergoing Accretion by the Addition of Successive Banks of Sand and Silt.

Photo taken at low tide, Blackpool, on the shores of the Irish Sea

as a broad fringe around land masses. They comprise—

- (i) *Coastal* and *shore deposits* of pebbles, gravel, and sand as well as broken-up coral, shells, etc.
- (ii) *Shallow water deposits* of sands, marine silts, and clays (usually blue in colour).
- (iii) *Deeper water deposits* of clays.

(*b*) *Pelagic deposits* or those derived from the shells or other hard parts of organisms living in the open ocean. The most widespread at the present day are the slimy grey or white *oozes*, named after the organism most prevalent (*e.g. Globigerina* ooze of the Altantic, *Pteropod* ooze, etc.). Most of these consist of calcium carbonate, but siliceous oozes

(*Radiolarian* ooze and *Diatom* ooze) also occur. In the deepest parts of the ocean a red clay may be found consisting of those parts of organisms most resistant to the action of solution (small calcareous bodies are dissolved by the sea-water before they reach such great depths) or volcanic material derived from volcanic dust storms, etc.

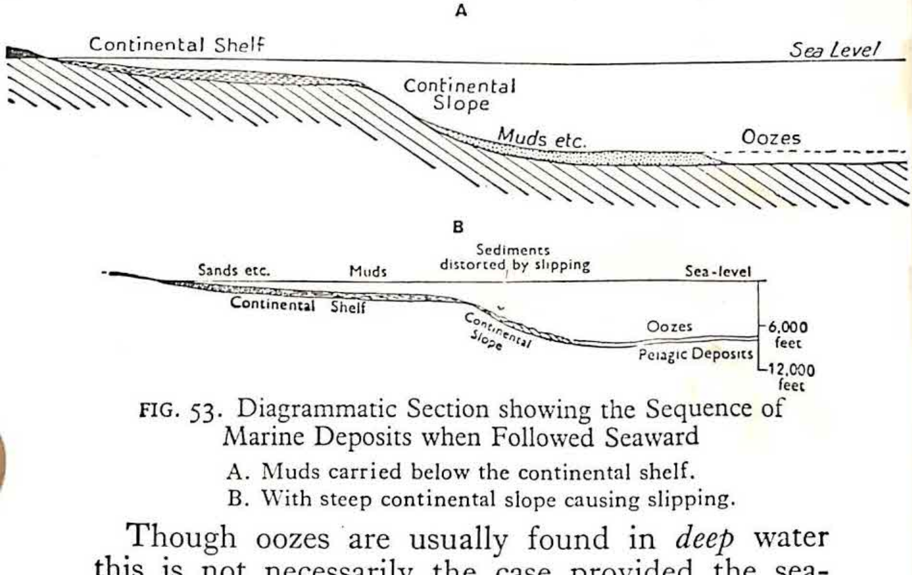


FIG. 53. Diagrammatic Section showing the Sequence of Marine Deposits when Followed Seaward

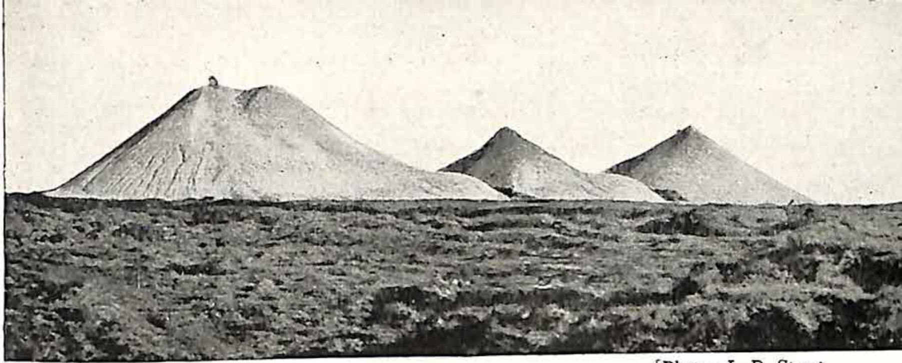
A. Muds carried below the continental shelf.

B. With steep continental slope causing slipping.

Though oozes are usually found in *deep* water this is not necessarily the case provided the sea-water is clear and free from sediment. The chalk which forms Britain's famed white cliffs of Dover was once an ooze formed in clear water but probably not far from land.

Except for shore deposits, it will be clear that marine deposits obey the law of superposition—the oldest at the bottom, the youngest at the top.

Action of Plants, Animals, and Man.—Plants, being themselves usually fixed, play little part in the transport of material, and animals but little more. Indeed, the function of plants by their rooting system,

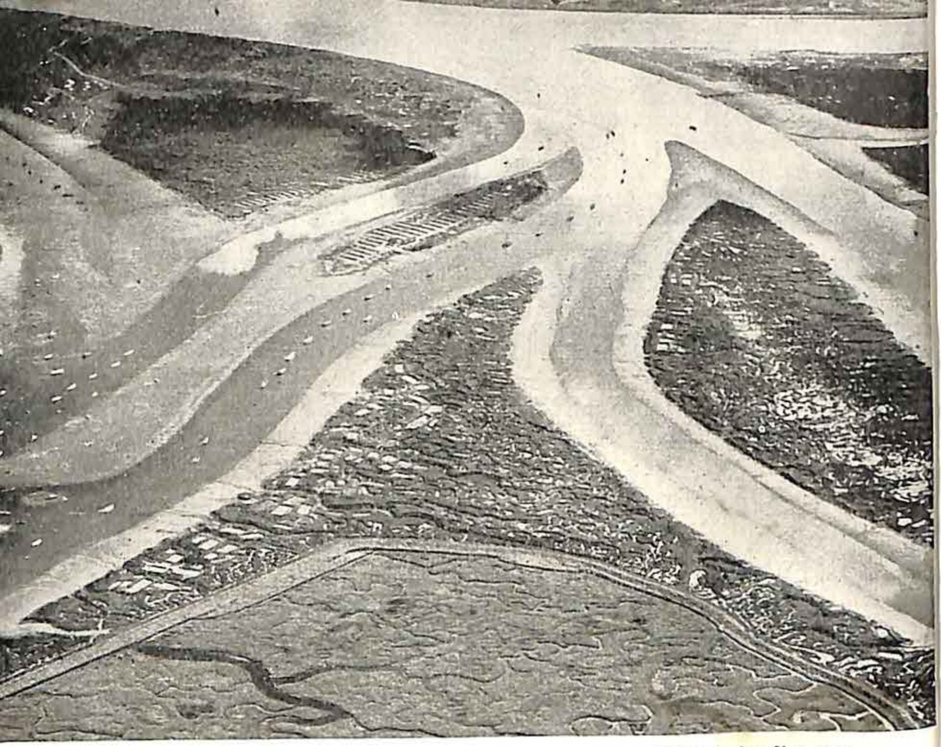


[Photo : L. D. Stamp

FIG. 54. Tip Heaps of Waste from China Clay Works near St. Austell, Cornwall, England

is usually the fixation of material such as sand which could otherwise be moved by the action of mud and water. Man, on the other hand, by removing vegetation assists the natural agents in their work of denudation and transportation. The action of man in building up tip heaps of waste material needs no comment, but more important, if less conspicuous, is the work of dredging rivers and channels whereby the natural carrying power of the current and tide is increased. Man often encourages the deposition of material in estuaries by forming low embankments behind which silt and mud steadily accumulate after each tide.

Sedimentary Rocks and Fossils.—Oceans and seas cover over three-fifths of the earth's surface, and for this reason alone *marine* deposits would constitute the largest class. Most frequently the land is continously subject to denudation so that *aeolian* deposits are only formed on parts of its surface. *Glacial* deposits though important belong especially to certain epochs. *Fresh-water* and *estuarine* deposits are important and widespread and in these, as with marine deposits, the law of superposition holds in the majority of cases. So we may say in general

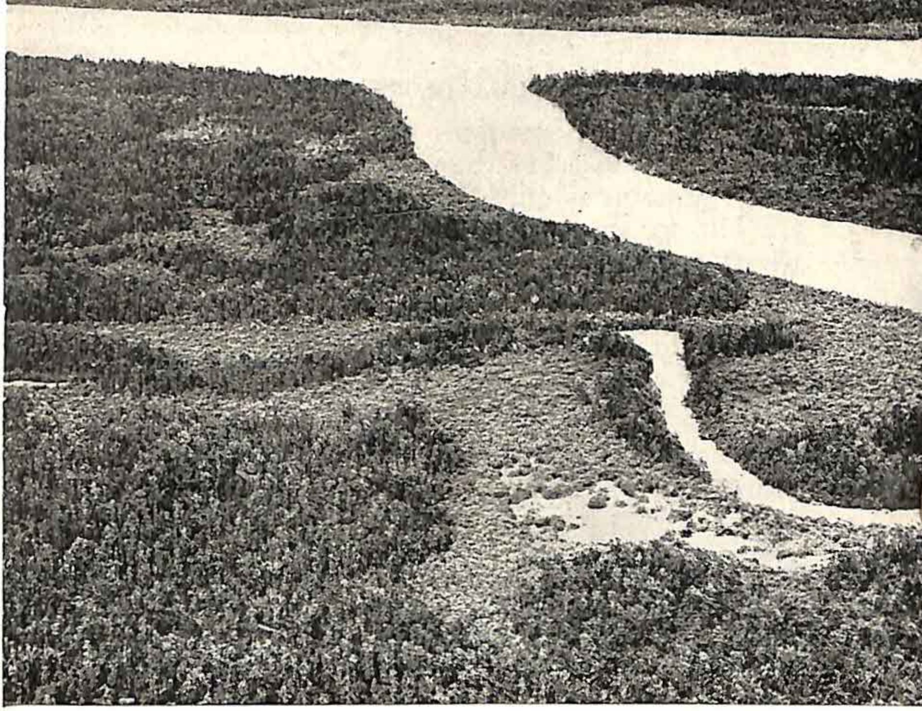


[*Photo : Aerofilms, Ltd.*

FIG. 55. Reclamation of Land by the Encouragement of Silting

Notice in the foreground an area of salt marsh which has been enclosed by an embankment. Silt is held up after each high tide, and this tract will eventually be converted to good pasture out of reach of high tides. Outside the embankment are areas which may be enclosed later (Coast of Essex, mouth of the river Thames, England).

that the members of the great class of the *sedimentary rocks* : (*a*) have been deposited under water and hence are occasionally called aqueous rocks ; (*b*) occur in beds or layers called strata (singular Lat. *stratum*=a layer) and hence are known as stratified rocks, sometimes as laminated rocks ; (*c*) the oldest layers are at the bottom, the youngest at the top, unless the rocks have been subsequently disturbed.



[Photo : Courtesy of Air Survey Co., Ltd.

FIG. 56. Aerial View of Part of the Irrawaddy Delta, Burma.

The mud between the delta streams is fixed by the growth of mangroves, and more silt accumulates, so that the mangroves give place to larger trees, and eventually dry land, out of reach of tides, results

It naturally happens that animals and plants when they die are entombed in the sediments being deposited around them. It may be, as with many marine molluscs, that they are buried where they lived on the sea bottom. In other cases the dead creatures are transported with the sedimentary material before being buried—it is a common sight to see leaves, branches, and even trees being swept along by a river in flood. Generally the soft parts of the animals and plants decay and only the harder parts remain. Sometimes only an impression remains in the rocks of the spot where an animal has laid; sometimes only the footprints of an animal are left to show where it once lived—footprints which are preserved by being gently covered by a coating of mud. All these remains or traces of animal and vegetable life are known as *fossils*. Animals and plants living to-day are being entombed and so forming recent fossils, but in the sedimentary rocks laid down long ago we find the remains of animals and plants quite different from those now found inhabiting the earth. These *extinct* creatures are often very curious, and it is possible to trace the gradual *evolution* of the animals and plants now living on the earth. Rocks may be found in one part of the country with fossils exactly like those found in different rocks deposited in quite a different part of the country—even another part of the world. Because the fossils are the same we presume that the two sets of rocks were deposited at the same time and so we have the great law, first stressed by the Englishman William Smith nearly 150 years ago, of *strata identified by fossils*.[1] Gradually geologists have built up the history of the earth and the evolution of life on its surface—a study which we call Historical Geology or Stratigraphy. We shall deal with this subject in a later section.

---

[1] William Smith was the great-great-great grandfather of F. K. Hare.

CHAPTER V

VOLCANOES AND IGNEOUS ACTIVITY

So far we have considered the slow processes of denudation and deposition which take place on the surface of the lithosphere, or earth's crust. We must now consider certain phenomena which are due to the existence, in the lower layers of the crust, of a layer where the temperatures are extremely high. For every 50 or 60 feet of descent into the crust there is an increase of temperature of about 1° Fahrenheit so that at a depth of a few miles the temperature must be sufficiently high to melt nearly all known rocks and minerals. It used to be thought that the earth consisted of a thin, solid shell surrounding a molten interior, and that where the crust became cracked some of the molten material was squeezed out. It is now proved that such a condition is physically impossible and that the heavy central core of the earth (the barysphere) is separated from the solid crust by a layer (probably about 700 miles thick) where very high temperatures are the rule. It is probable, however, that the rocks are not actually molten, but are kept in a plastic or almost solid condition by the intense pressure. Whenever there is, for some reason or other, a decrease in pressure some of the layer liquifies and constitutes a *primary magma basin*. There is then a tendency for the liquid rock to move and naturally the molten rock follows any crack or line of weakness. It may force up the solid layers of the crust to form an arch and then the mass slowly solidifies in the cavity so formed. Such a mass would form a *boss*, *batholith* or *bathylith* and would appear in section as shown in Fig. 57.

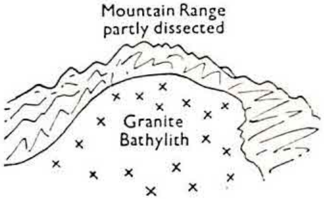


FIG. 57. Sections through Batholith or Bathylith

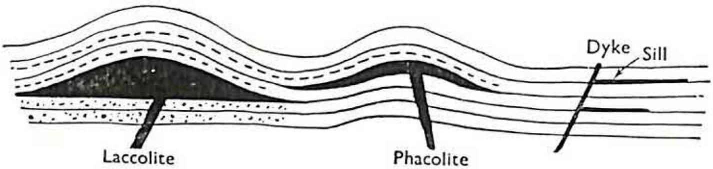


FIG. 58. Section through a Laccolith or Laccolite and Sills

Naturally such a mass would cool very very slowly, and the minerals would have time to grow into large crystals. *Granite* is such a rock and it is only after long ages of denudation that the boss or batholith of granite would be exposed at the surface. Such a batholith, when still liquid, might be described as a secondary magma "basin" and it is probable that the liquid mass or magma in its movement actually dissolves some of the rocks through which it forces its way—a process known as *magmatic absorption*—and the composition of the original magma may be changed. In any case the rocks around the mass are changed or "metamorphosed," and there is a "*metamorphic aureole*" round such a mass as a granite boss. Just as when a sticky mass of jam is being boiled both the "scum" of various impurities and the most liquid portions of the whole rise to the surface, so in the case of a batholith there is the equivalent of a scum and also certain parts which remain fluid long after the main mass. The fluid portions are forced through cracks in the crust and may there solidify as wall-like masses (called *dykes*) or may be intruded as thin sheets along the bedding planes of sedimentary rocks (forming *sills*). The liquid mass of a sill may swell out to form a thick mass or *laccolith* (or *phacolith*). A laccolith is really a large blister filled with molten rock, a *phacolith* a lens-shaped mass occupying the middle of a syncline or anticline. In other cases the molten rocks actually reach the surface of the earth through the cracks and may then be poured out as sheets of lava. If, instead of a crack, the molten rock escapes through a hole a volcano is formed, the hole being the neck of the volcano.

At the same time the normally much more sticky " scum "—in some cases rendered very fluid by the presence of certain very active gases—may be forced also through cracks. Sometimes it seems that gases passed through the cracks and minerals crystallized from them on the walls of the cracks ; in other cases watery solutions at very high temperatures from which the minerals also crystallized In either case the walls of the crack were lined with crystals first and common crystals occurring in this way are of quartz. Then the crevices in the centre of the crack became filled with crystals of other types and many of the metallic minerals so much valued by man occur in this way—the ores of gold, silver, lead, zinc, copper, tin, etc. Such a filled-in crack is called a *vein* (a metallic vein if metallic minerals are present as well as the useless gangue minerals). Sometimes the vapours carrying the metals penetrated through a whole mass of rock and formed a *stockwork*. Thus metallic minerals are commonly associated with districts which have been affected by mineralizing waters and vapours—that is, in "highly mineralized" districts frequently associated into volcanoes.

Returning now to volcanoes, we may consider first of all *fissure eruptions* in which masses of molten rock (lava) well quietly out of fissures and flow steadily over the surrounding country as great sheets sometimes stretching for hundreds of miles. Not until it is considerably cooled does the lava become sticky at the ends and cease to flow. Geographically, such lava flows are very important not only because of the vast area they cover, but because of the frequency with which they have weathered to form fine fertile soil. Good examples are the Deccan lavas of India, which cover over 200,000 square miles, or the Antrim lavas of Ireland, which cover 1,500.

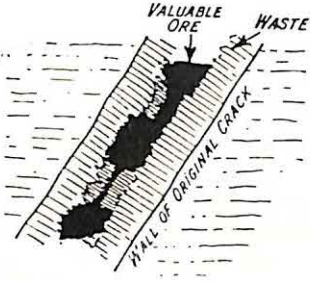
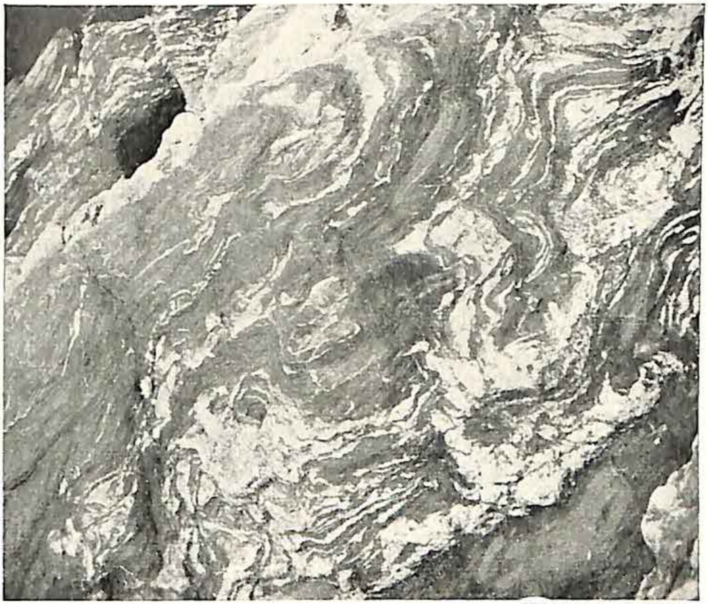


FIG. 59. Section through a Vein

Volcanoes of the cone type originate with the clearing of a vent in the ground, usually by a great explosion which throws into the air masses of stone, pebbles, dust, ashes, etc., together with fragments of molten rock which are whirled round in the air and solidify to fall as *bombs*. This débris, blown out with great clouds of gases and steam, naturally falls back to earth and forms a cone around the vent. Generally at a later and quieter stage lava wells up and flows as streams down the sides of the ash or tuff cone. Some of the lava may solidify and clog the vent or neck forming a volcanic plug which may



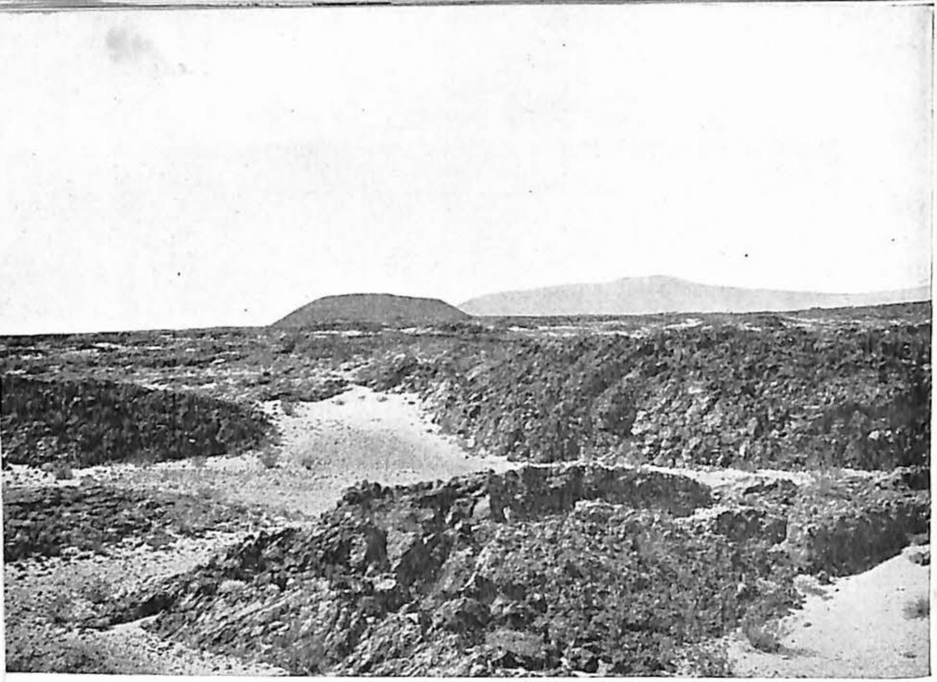
[Photo : L. D. Stamp

FIG. 60. Shales or Slates penetrated by Innumerable small veins of Quartz and the whole then highly folded

If bearing metallic minerals this would form a stockwork. (Newquay, Cornwall.)

later be exposed by the denudation of the softer ashes all round. A later eruption may blow the whole structure almost to pieces, or a subsidiary volcano may grow near on the sides of the old one. Frequently the effect of the later eruption is to blow away one side or wall of the crater.

The later stage in the evolution of a volcano is that known as the *solfataric* stage when only gases and vapours are emitted from holes in the floor of the crater which is otherwise filled up. This is the dormant stage and when all signs of activity

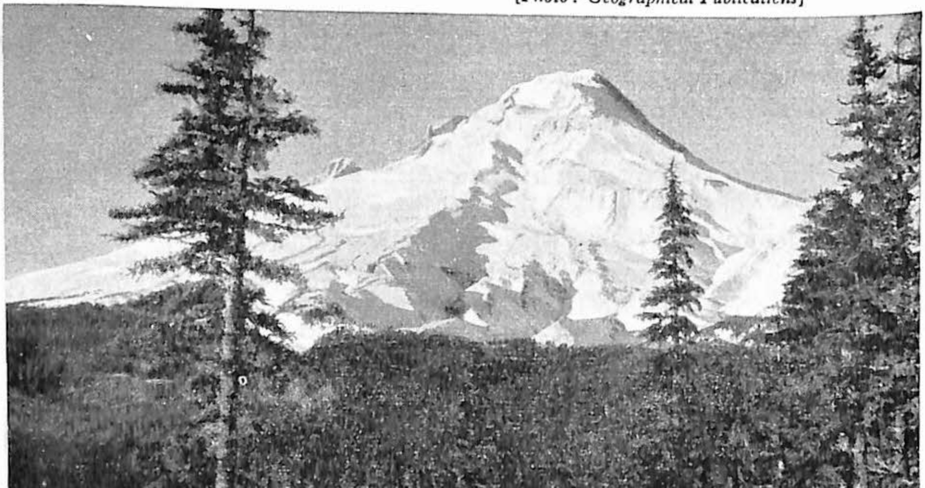


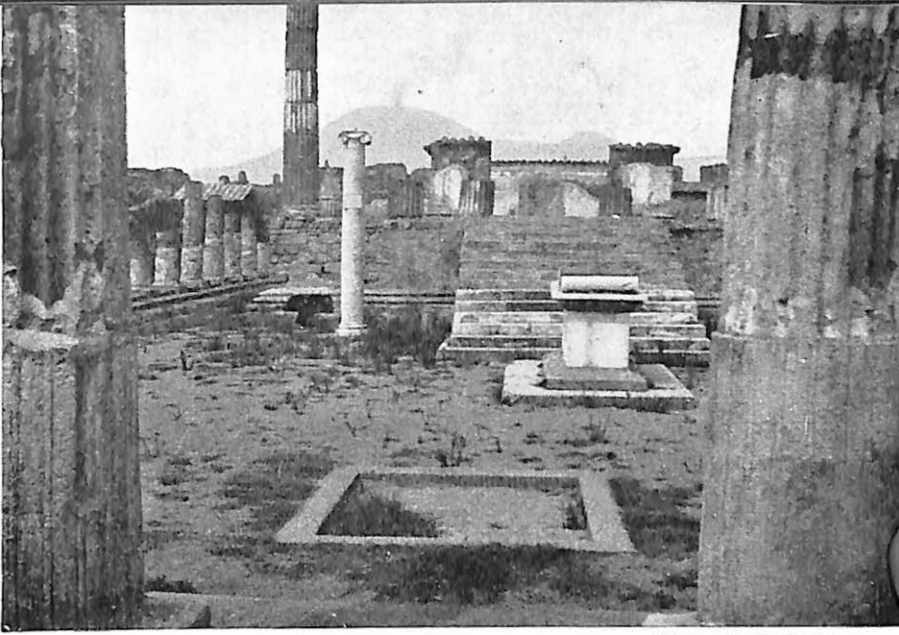
[*Photo : L. D. Stamp*

FIG. 61. The End of a recent Lava Flow, Arizona, U.S.A.

FIG. 62. Mt. Hood, Oregon, U.S.A., A Good Example of an extinct Volcano with a symmetrical lava cone

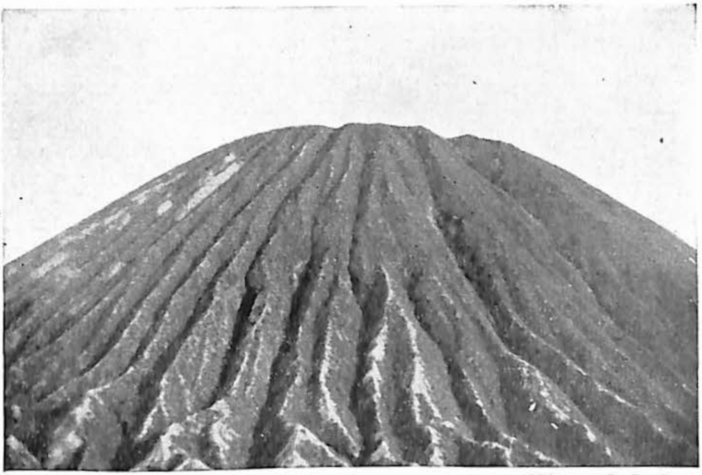
[*Photo : Geographical Publications*]





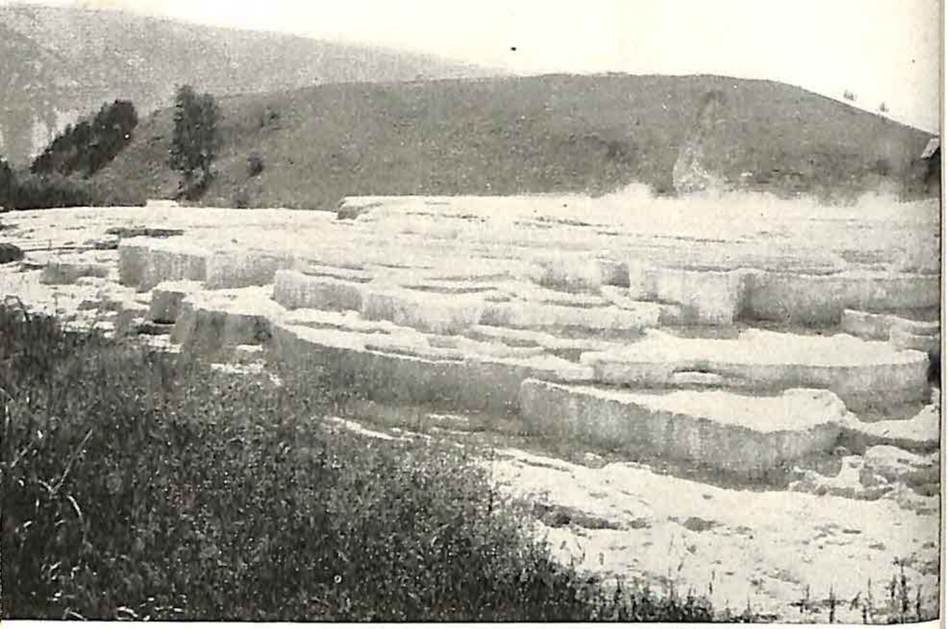
[Photo : L. D. Stamp

FIG. 63. The Ruins of Pompeii, destroyed by an Eruption of Mt. Vesuvius (seen in the background), being buried under ashes in A.D. 79.



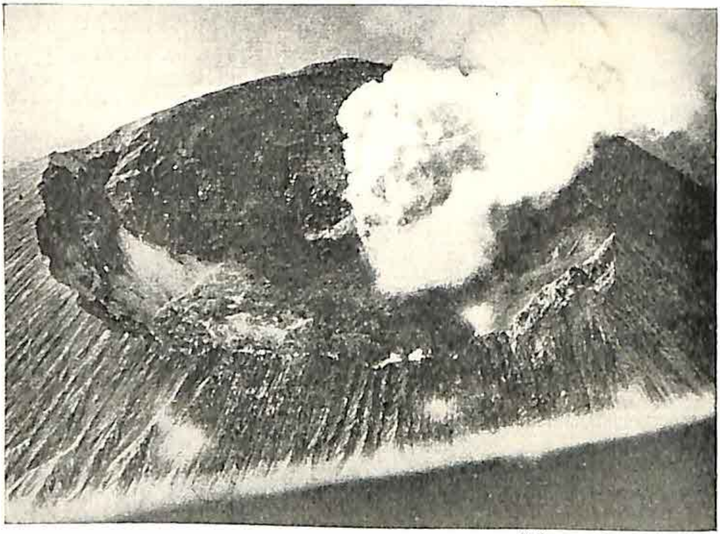
[Photo : L. D. Stamp

FIG. 64. A Young Tuff or Ash Cone already partly denuded by tropical rains near Mt. Bromo, Java



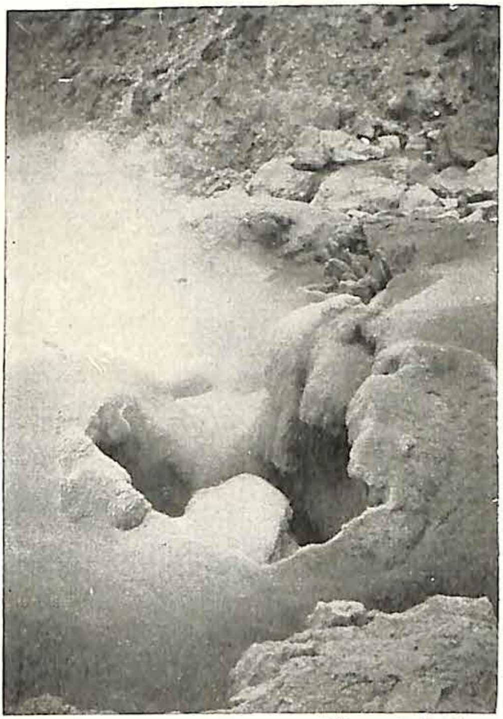
[Photo : L. D. Stamp

FIG. 65. Deposits of the Mammoth Hot Springs, Yellowstone



[Photo : Aerofilms, Ltd.

FIG. 66. Mt. Vesuvius, an Active Volcano rising out of the breached crater of a former volcano, Monte Somma



[*Photo : L. D. Stamp*

FIG. 67. Details of a Vent, lined with Sulphur Crystals, giving forth Sulphurous Gases

Crater of Mt. Papandajan, Java.

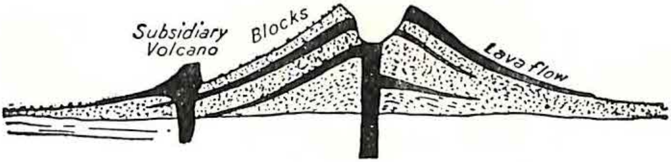
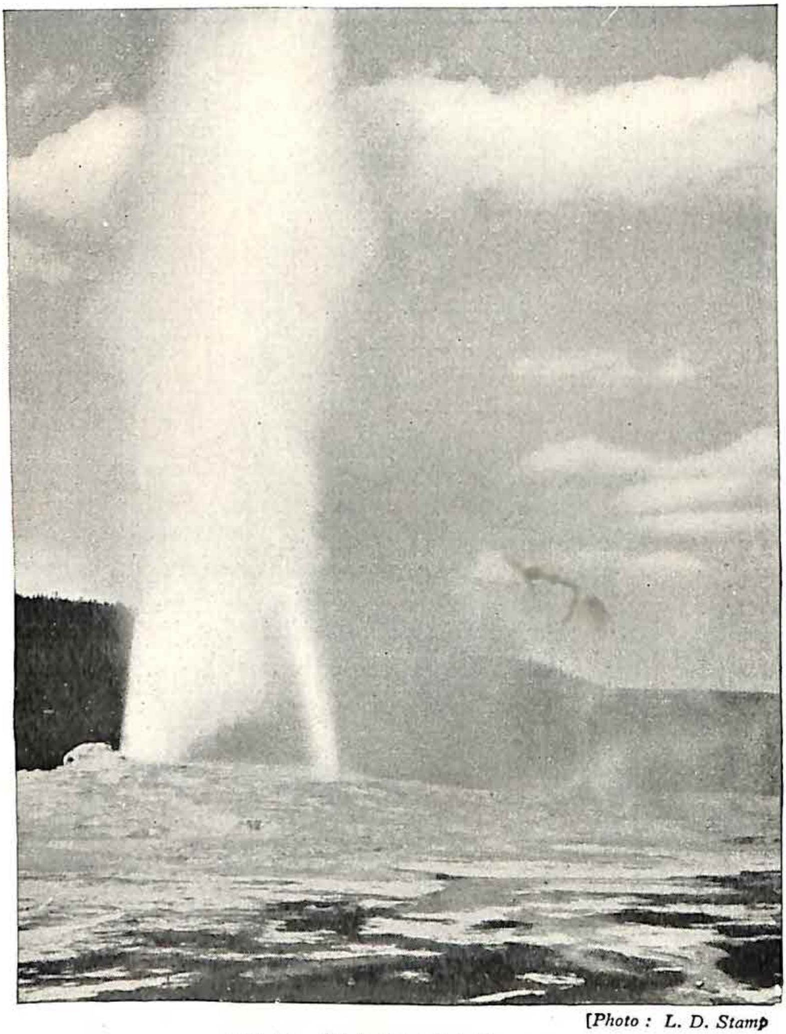


FIG. 68. Section through a Typical Volcano, Mt. Popa, Burma

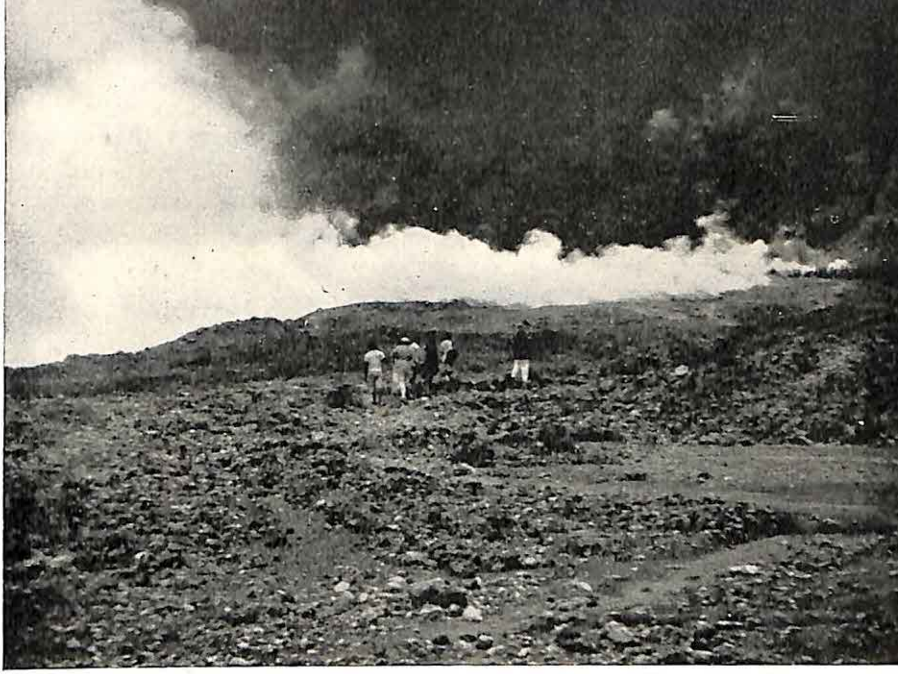
3*



[Photo : L. D. Stamp

FIG. 69. Old Faithful Geyser.

The column of water reaches a height of 130 feet.



[Photo : L. D. Stamp

FIG. 70. The Solfataric Stage—Inside the Crater of Mt. Papandajan, near Garoet, Java

cease the volcano becomes extinct. The crater may then be occupied by a lake or, if the crater is breached, be covered with vegetation.

There are other phenomena associated with volcanic districts, especially with those which have reached a solfataric stage of activity. One is the occurrence of *hot-springs*, usually of water highly charged with mineral matter (*mineral springs*). Sometimes the water accumulates in underground chambers and is then emitted with explosive violence as a *geyser*. Some geysers are very regular in their eruptions, a good example being Old Faithful in the Yellowstone National Park of the United

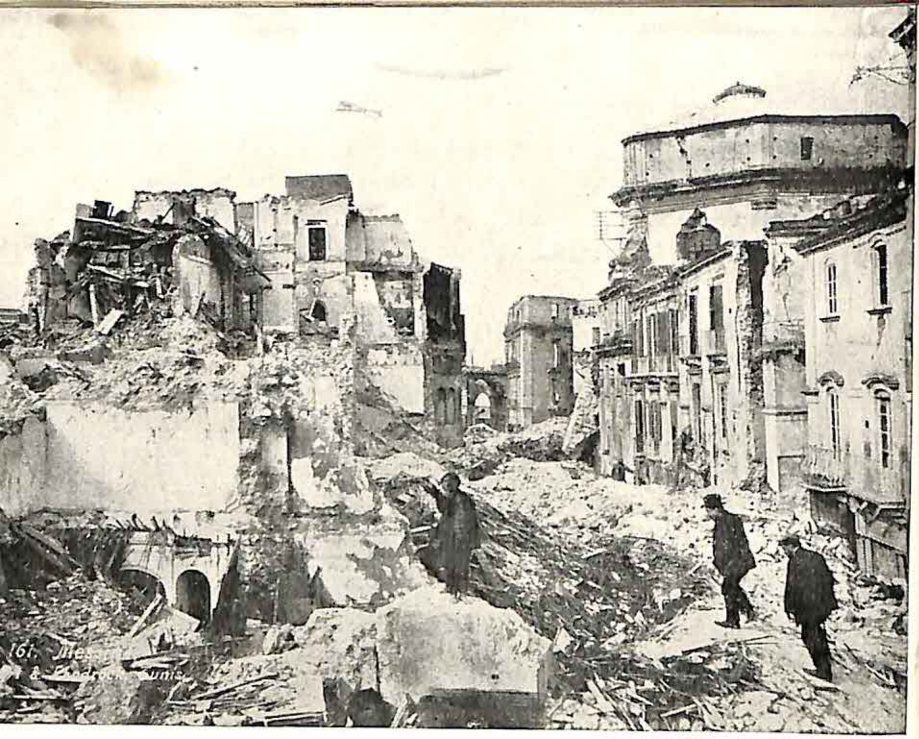
States, which erupts every 66 minutes. Most mineral springs leave a deposit when they reach the surface, sulphur compounds being common (as with solfataria also). Other deposits are siliceous.

CHAPTER VI

EARTHQUAKES AND MOUNTAIN BUILDING

Earthquake.—The French term "tremblement de terre"—a trembling of the earth—is a better descriptive name than our English "earthquake." Earthquakes are often associated popularly with volcanoes. It is true that an outburst of volcanic activity is usually accompanied by slight earth tremors or earthquakes, but the more serious earthquakes are generally not connected directly with volcanoes.

In the last section we referred to the movement underground of great masses of molten rock. Such movements would be felt at the surface as earthquakes. We have seen that the general effect of denudation is to wear away the land and deposit the material over the floor of the ocean. Thus the weight of rock on the land is gradually decreased and the weight of sediment on the sea floor gradually increased. There comes a time when the part of the crust over the land is thus weakened and presses less severely on the lower layers. An unstable condition results and earthquakes may follow. Earthquakes are often found to be connected with great cracks or *faults* in the earth crust. On one side of the fault the land tends to move up, on the other to move down, and great tremors like waves are set up radiating from the *epicentre* of the earthquake. Sometimes the rocks on either side of a fault move laterally. Sometimes parts of the crust are folded and again earthquakes result.



[*Photo: E.N.A.*

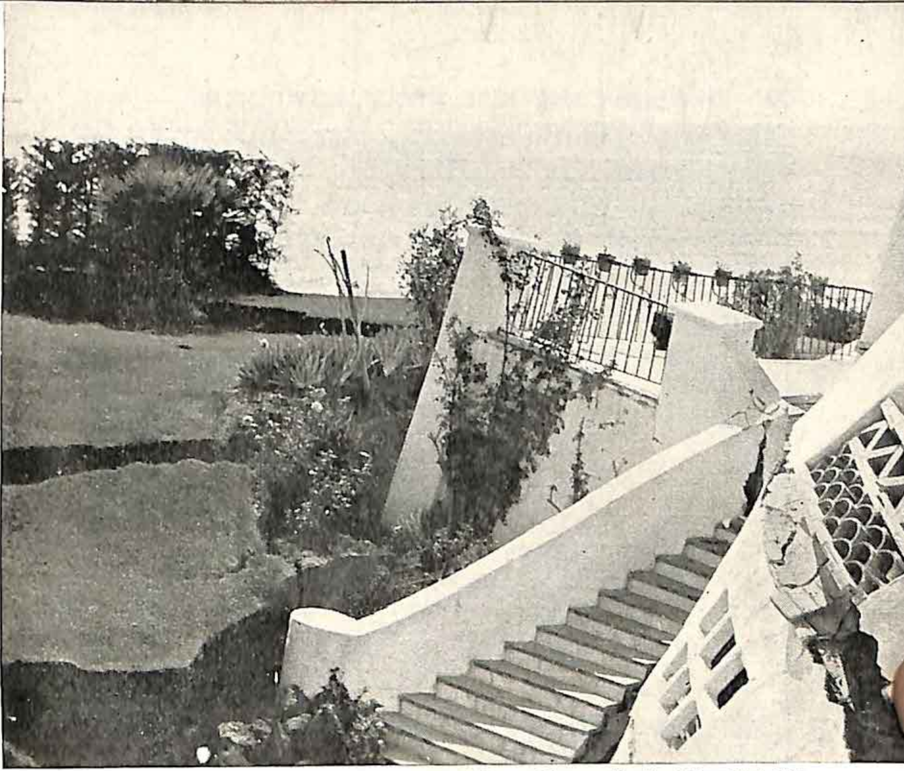
FIG. 71. Destruction of Messina after the Earthquake of 1908

Severity or Intensity of Eathquakes.—The severity of earthquakes is measured according to scale thus:

Rossi-Forel Scale.

Intensity	10	Disastrous—fissures in ground, ruin and disaster.
,,	9	Extremely strong—destruction of buildings.
,,	8	Very strong—fall of chimneys, cracks in walls.
,,	7	Strong—overthrow of moveable objects.
,,	6	Fairly strong—sleepers awakened, clocks stopped.
,,	5	Moderate—felt by everyone, disturbance of furniture.
,,	4	Feeble—felt even by persons in motion.
,,	3	Very feeble—felt by most persons at rest.
,,	2	Extremely feeble—felt by a few persons at rest.
,,	1	Microseismic—recorded by instruments only.

Earthquake Belts.—There are certain parts of the earth's crust which, at the present day, are especially subject to earthquakes. These are really lines of



[*Photo: Literary Services (Mondiale), Ltd.*

FIG. 72. The Palatial Bungalow of the Mayor of San Clemente California after the earthquake which caused great cracks (faults) of which one is seen in the lawn to the left, whilst the house itself actually settled down into another (1933).

weakness in the earth's crust. Such a line runs right round the Pacific Ocean and is especially notable where high mountains are close to great ocean deeps. Serious earthquakes round this belt have included :

Tokyo and Yokohama (Japan) 1923	140,000 killed
San Francisco (U.S.A.), 1906	San Francisco largely destroyed
Napier (New Zealand), 1931	Napier ruined
Nicaragua, 1931	Capital, Managua destroyed
Lima (Peru), 1868	25,000 killed
Valparaiso (Chile), 1906	2,500 killed

Other serious earthquakes have been associated with the fold ranges of the Himalayas and its branches (Quetta, Baluchistan in 1935 and Pegu, Burma in 1930 were particularly severe), others with fold ranges in Europe (*e.g.* Messina, Italy, with the Apennines in 1908). The British Isles are fortunately stable except for small earthquakes associated with Scottish fault zones, just as Canada has few earthquakes except along the western fault zones.

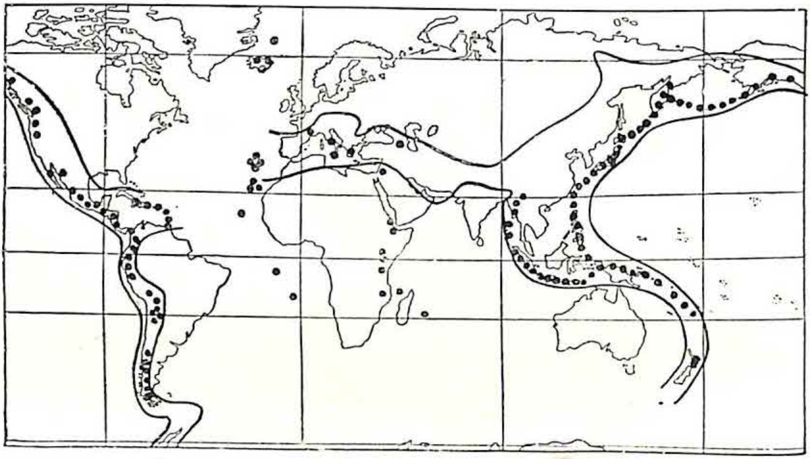


FIG. 73. Map of World showing Volcanoes (active and recently extinct—dots) and Earthquake Belts.

Effects of Earthquakes.—Amongst the more important effects of earthquakes, apart from the destruction of property are:

(1) Formation of faults and the movement of the earth's crust on either side.

(2) The raising up of portions of the sea-floor to form dry land, or the elevation of tracts of country, or the great shallowing of sea for the same reason.

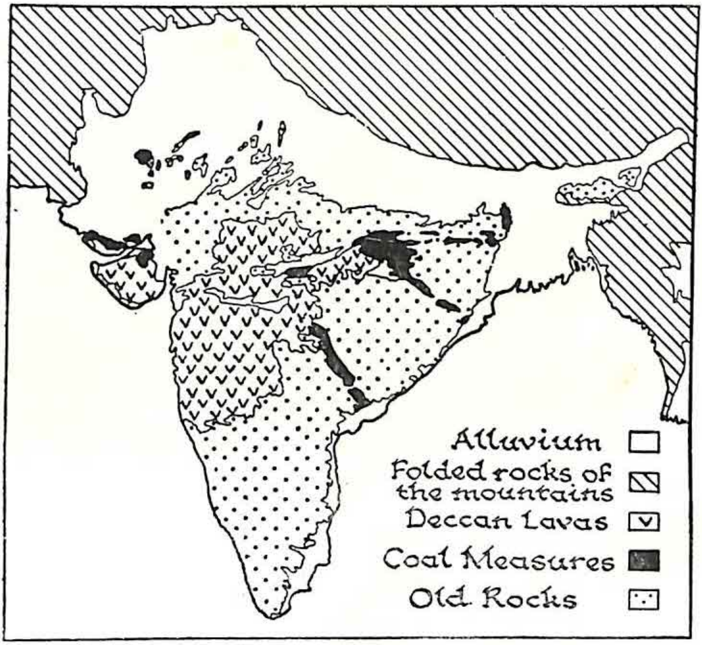


FIG. 74. Structure Map of India

(3) The submergence of portions of the land or the bodily depression of parts of the surface.

(4) The folding of parts of the surface so that some areas are raised, some depressed, and a gentle wave-like surface produced.

(5) The causation of great falls of rock from mountain sides, the blocking of valleys by débris, the sliding of masses of soft rock, and probably the sliding of masses of sediment on the steeper parts of the sea-floor.

Earth Movements and Mountain Building. — At present the earth is enjoying a quiet period in its history, and severe earthquakes are few. There

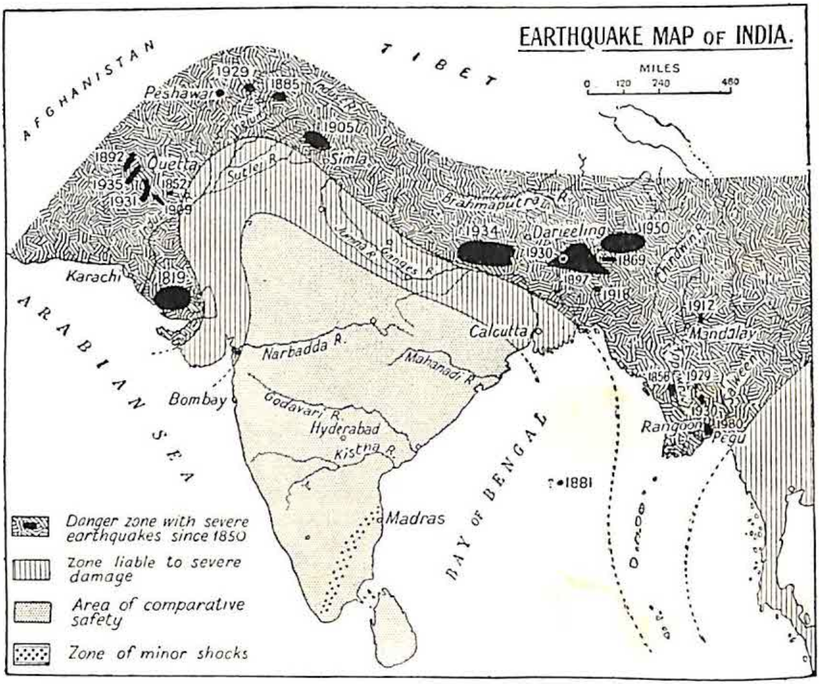


FIG. 75. Earthquake Map of India

(*after W. D. West*).

Notice how the earthquakes occur almost entirely in the young folded rocks of the Himalayas. The peninsula, a stable Pre-Cambrian shield, is almost free of them (*cf.* Fig. 74).

have been times in the past, fortunately before man inhabited the earth, when the whole crust must have been shaken continuously by a succession of earthquakes. Such a period of instability is called an *orogenic* period or period of mountain building. It is difficult for us to conceive such a period, when our great mountain chains were being created and when the rocks of the earth's crust were bent or folded, crushed and cracked or broken ; but we can see the results of such movements. Other movements, as when great masses of land are raised to form plateaus without being folded, are called *epeirogenic*.

Dip and Strike.—When sedimentary rocks are deposited on the floor of a sea or lake the beds or strata are practically horizontal. The first and simplest effect of earth-building movements will be to raise such a series irregularly —one part more than another, as shown in Fig. 76. The strata then slope in one direction and the slope of the *bedding planes* is called the *dip* of the rocks. The dip is measured in degrees from the horizontal. A line drawn at right angles to the direction of dip is the *strike*. When a series of strata are seen in a cliff they will appear horizontal if the direction of the cliff is parallel to the strike.

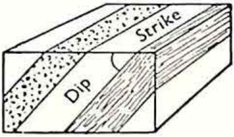
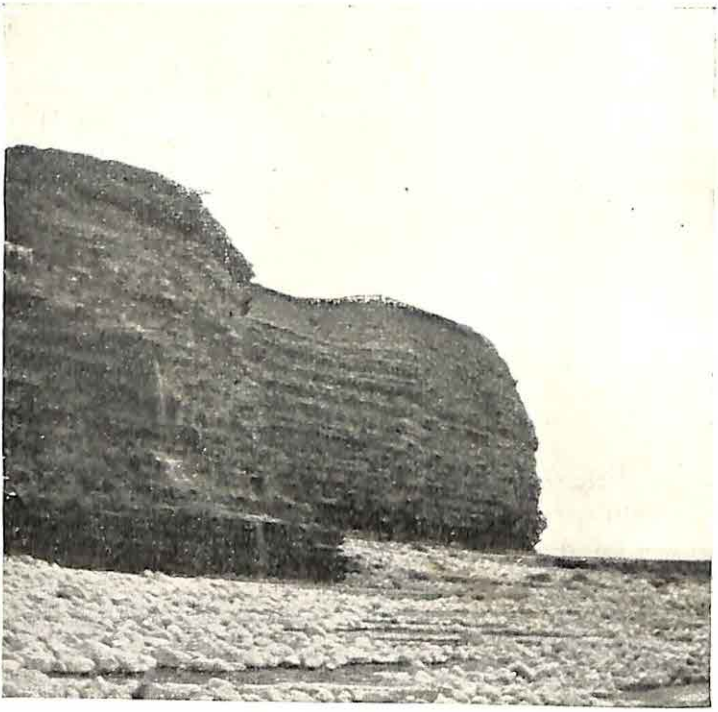


FIG. 76. Diagram Illustrating Dip and Strike

Regions of Compression—Folding.—In mountain-building movements certain lines of weakness on the earth's crust become regions of compression where the rocks are compressed laterally and many varied *folds* are formed. The simplest folds include the *anticline* or arch, and the corresponding *syncline* or trough. If the two *limbs* of the fold slope or dip equally the fold is said to be *symmetrical*; if, as more often happens, one limb dips more steeply than another, the fold is said to be *asymmetrical*.

Notice that in Figs. 78 and 79 the upper parts of the folds have been worn away by the ordinary processes of denudation. This is nearly always the case, so that an anticline or arch of the strata does not correspond necessarily with an arch or ridge of the land and only rarely does the slope or dip of the



[*Photo : L. D. Stamp*

FIG. 77. Almost Horizontal Strata

Cliffs, coast of Glamorgan, South Wales, in Lower Lias.

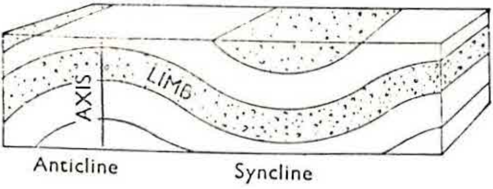
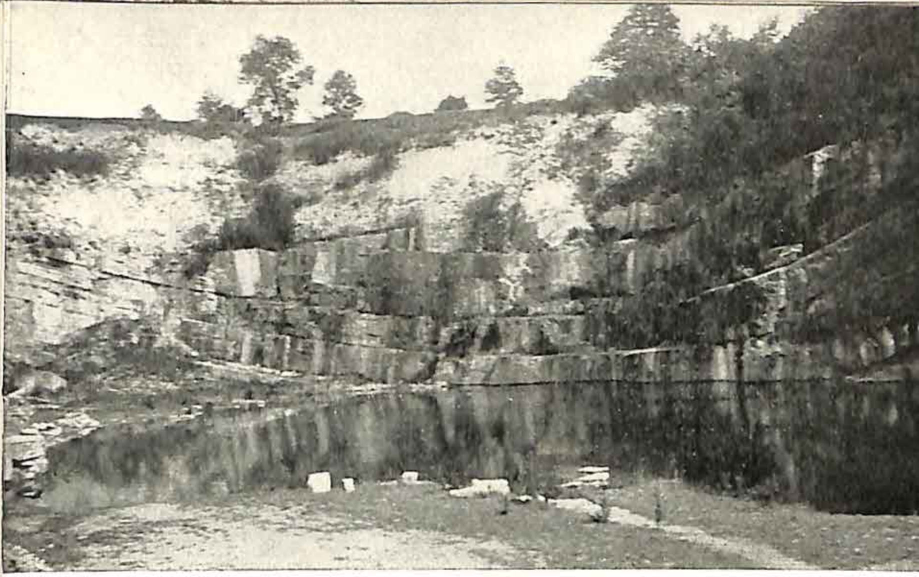


FIG. 78. Diagram of Anticline and Syncline



[*Photo : L. D. Stamp*

FIG. 79. A Simple Syncline in Limestone, Belgium

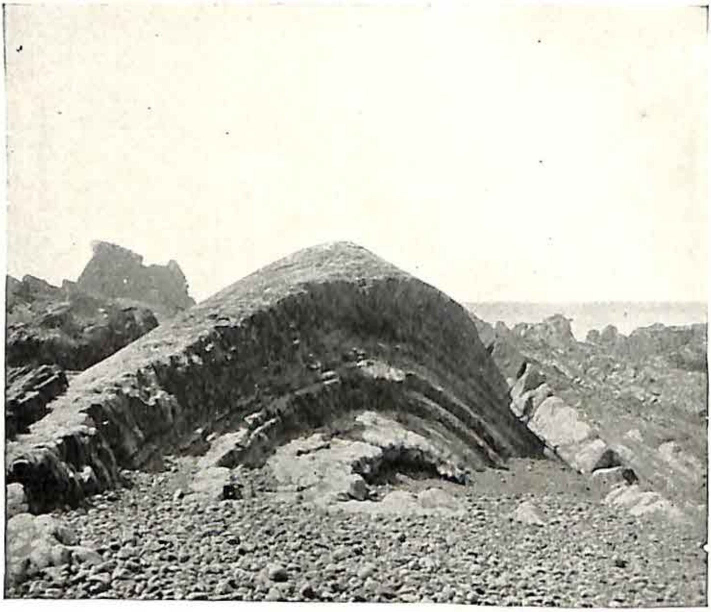
Notice that the limestone beds are abruptly truncated and overlain by a thickness of white, crumbling rock. This constitutes an unconformity.

land surface correspond with the slope or dip of the rocks. This is very important.

A simple anticline may slope *as a whole* in one direction. It is then said to *pitch*. Some anticlines pitch in both directions ; similarly a syncline may be replaced by a basin-shaped structure.

In more highly folded districts, one limb of the fold may be vertical ; or one limb may be folded right over the other, producing an overfold. In this case the sequence of rocks in the overfolded limb will be reversed, with the youngest at the bottom.

Sometimes in highly folded areas the rocks are tightly folded together and it is difficult to tell which are anticlines and which synclines. In such



[*Photo : L. D. Stamp*

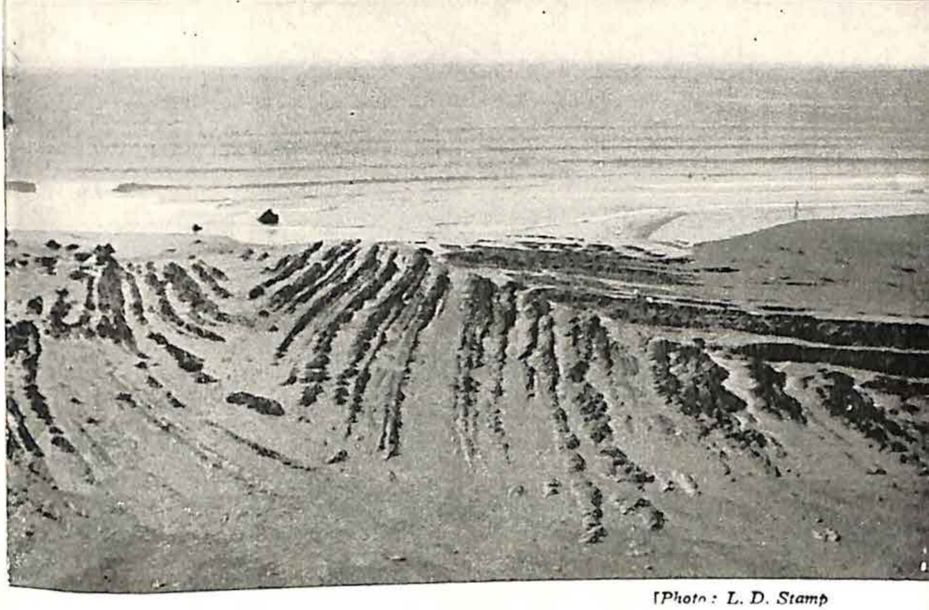
FIG. 80. An Anticline in Sandstone, Bude, South-west England

This anticline is pitching slightly towards the camera.

isoclinal strata the rocks all *appear* to dip in the same direction.

If we take a section across a mountain range the rocks may be folded into a huge arch of which each limb is highly folded. Such a structure is called an *anticlinorium*. The corresponding structure is a *synclinorium*. The section often rather resembles a fan, and so reference is sometimes made to fan-shaped structures.

Returning for a moment to gently folded areas, sometimes a simple anticline stretches over many miles of country, when it is called a *geoanticline*,



[Photo : L. D. Stamp

FIG. 81. Rocks exposed on the Foreshore, north of Bude, South-west England, showing a denuded syncline (left), and a denuded anticline (right), pitching towards the sea.

the corresponding structure being a *geosyncline*. A geosyncline has, however, other and more important features. It seems that when a geosynclinal trough is formed on the earth's surface, the centre continues to sag slowly and to allow huge thicknesses of sediment to be formed. The whole becomes unstable and "buckles up" so that a geosyncline becomes replaced by a great mountain chain. Sometimes a fold occurs which seems only to have one limb (as in Fig. 84). British workers often call such a structure a *monocline*, a term used by American writers for evenly dipping rocks also called a *homocline*.

Regions of Compression. -- Faulting.—It is unlikely that a series of rocks, some relatively hard and rigid, some softer and more yielding, would be folded as described above without actually breaking in places. Such breaks are known as *faults* (German: verwerfungen, bruchen). In regions where the rocks have been compressed *reversed faults* will be found.

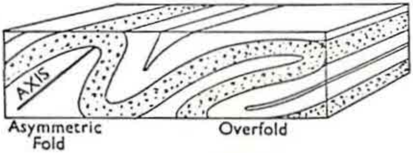


FIG. 82. Diagram of Overfolding

The angle which the *fault plane* makes with the vertical is called the *hade* of the fault, the vertical deplacement (*c–d* on the diagram) is called the throw. There is clearly a *down-throw* and an *up-throw* side. The rocks on either side of a fault plane are often striated or polished by the movements (*slicken-sides*). In other cases the rocks may be ground or broken into a *fault-breccia*. In still other cases, especially in soft rocks, the fault may be invaded by mud, and a *mud vein* formed. This is very important in oilfields, as the mud vein effectively seals off the oil. Faults which are roughly parallel to the direction of the dip are

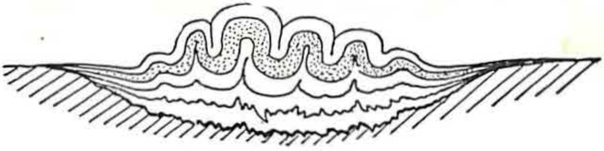


FIG. 83. A Geosyncline Crumpled to form a Synclinorium

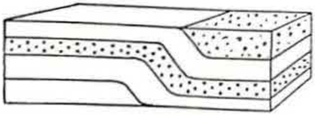
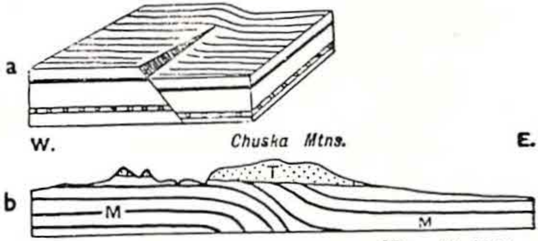


FIG. 84. A fold with only a single limb

called dip faults, those parallel to the strike are strike faults.

In highly folded areas, where a great series of rocks is folded right over another, the lower limb often gives way and the one series of rocks slides right over the other by a *thrust fault*, the plane of the fault being near the horizontal. In addition to a great thrust many little thrusts may also be developed, producing *imbricate* structure.



[From Wooldridge and Morgan

FIG. 85. (*a*) Single-limbed fold passing into Normal Fault; (*b*) A similar fold, eroded and covered by Tertiary Sandstone (T)

Regions of Tension—Faulting.—When some districts are being tightly folded, it is only natural that others should be in a state of tension. The rocks can scarcely be pulled out, but in such areas faults develop which we call *normal* faults. Not infrequently a considerable tract of country may be

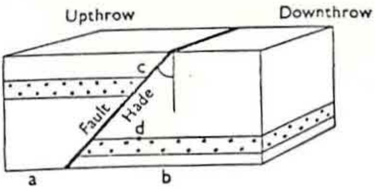


FIG. 86. A Reversed Fault—the group of rocks on the left (*a*) have been partly forced over the group on the right (*b*)

let down between two parallel normal faults. A *rift valley* (trough or graben) is thus formed. In other cases a block of country surrounded or partly surrounded by normal faults may stand up above the general level as a *horst* or faulted block mountain.

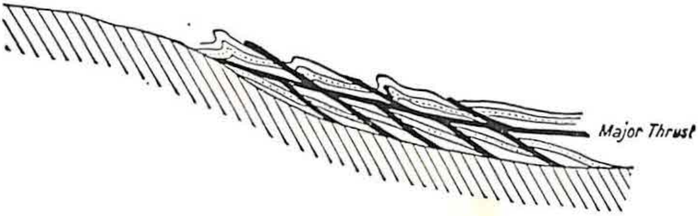


FIG. 87. Thrust Faults and Imbricate Structure

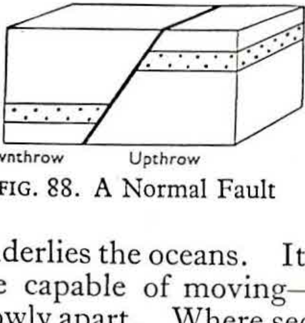


FIG. 88. A Normal Fault

Mountain Building.—Certain areas of the earth's crust act as rigid masses or stable blocks, and it is believed by some that these masses are like islands of rather lighter rocks (sial) resting on a general layer of heavier material (sima) which underlies the oceans. It is believed that these masses are capable of moving—drifting slowly together or slowly apart. Where sediments have been deposited

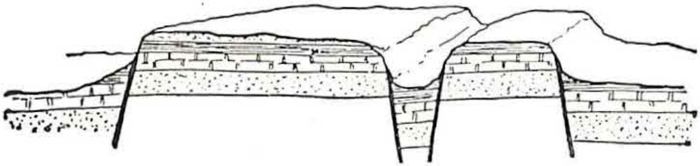


FIG. 89. Diagram of Block Mountains and Rift Valley

in the ocean basin between two masses, these sediments will be highly folded if the masses drift together and a great mountain chain results. This is illustrated in Fig. 83. If on the other hand one mass remains fixed and the other drifts towards it, a complex mountain chain will also result, but it will be structurally different (Fig. 90). The Alps and the Himalayas are believed to have originated in this way by the drifting of the ancient blocks of Africa,

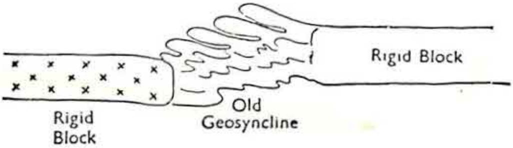
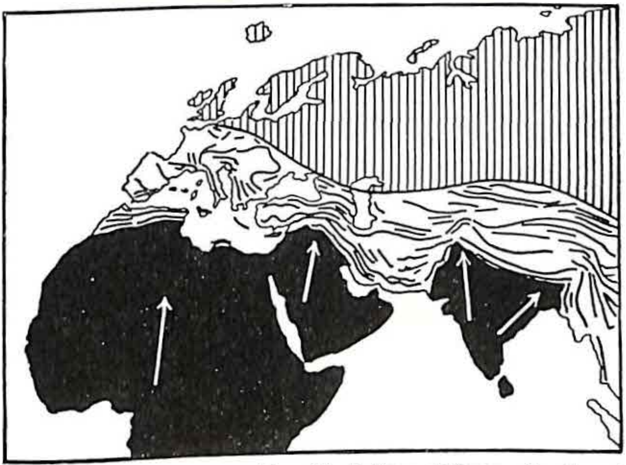


FIG. 90. Diagram showing the formation of a Mountain Chain by the drifting together of two Continental Masses.

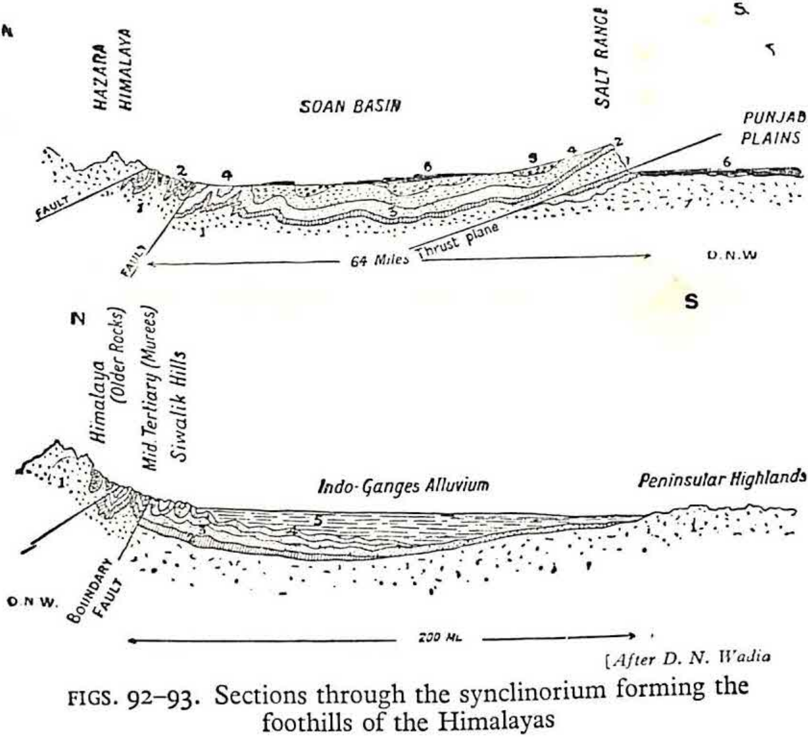


[*From Wooldridge and Morgan, after Argand*

FIG. 91. The supposed origin of the Alpine—Himalayan system

Arabia, and Southern India towards the old blocks of northern Europe, Russia, and Northern Asia.

With such movements overfolding and thrust faulting will occur and the structure (far more common than formerly supposed) is known as *alpine* structure.



[After D. N. Wadia

FIGS. 92–93. Sections through the synclinorium forming the foothills of the Himalayas

Great and complex *mountain knots* occur when two great systems of folding cross one another.

Periods of Mountain-Building.—There have been periods, to which we shall refer later, when great mountain-building movements have taken place, and other periods in the earth's history when quiet conditions have prevailed. Areas which have been very highly folded at one period have then been worn down by the agents of denudation, and have at a later date constituted stable blocks. Thus the Highlands of Scotland were intensely folded at an early date and have since formed a stable block. Other well-known cases of the same sort are the great Canadian Shield and the Plateau of Peninsular India. It is quite incorrect to refer to these old blocks as "unfolded areas." They are really very intensely folded.

In some cases later folding movements have the effect of increasing the intensity of earlier folds, in which case a fold may be partly of one age, partly of another.

In other cases the effect of later earth movements is simply to develop cracks in the old rigid blocks—sometimes so many as to absolutely shatter the old rocks. At times the cracks follow one or more general directions and produce *jointing* in the rocks (the major system being known as *master joints*). More often there are cracks which radiate from a centre and at the same time cracks which run concentrically round the centre like a spider's web. Such a type of cracking is seen if one hits a sheet of safety glass with a very heavy hammer. The importance of these cracks is that they form lines of weakness along which the agents of denudations are able to work more easily.

Sequence of Events in a Great Mountain-Building Movement.—When we study the sequence of events of the great orogenic periods it seems that the first stage, that is, after the period of lithogenesis or accumulation of the necessary sediment, is one of moderate volcanic activity—the first signs of the gathering storms. Then comes the great period of earthquakes and folding, during which there are huge underground movements of molten material which is often injected into the "core" of the chief anticlines where it solidifies to form granite. The later stages are marked by minor intrusions and the development of volcanic activity. In the great mountain chains of the Andes and Rockies folding movements have ceased, but some active and many extinct volcanoes remain to mark the last phase. As soon as the period of orogenesis is in active swing, the wearing away or sculpturing of the mountains begins.

Slow Movements of Elevation and Depression.—It is important to remember that, even in periods when the earth is quiet or comparatively quiet, slow movements of elevation and depression which gradually change the level of the land relative to the level of the sea are taking place. These are going on in many parts of the world even at the present day. They may sometimes be due to the operation of the principles of *isostasy* or *compensation*—as material is removed from the land by denudation so the burden of rocks is lighter and the land gradually rises whereas the level of the sea floor gradually sinks as the burden of sediment on it

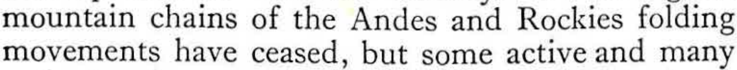
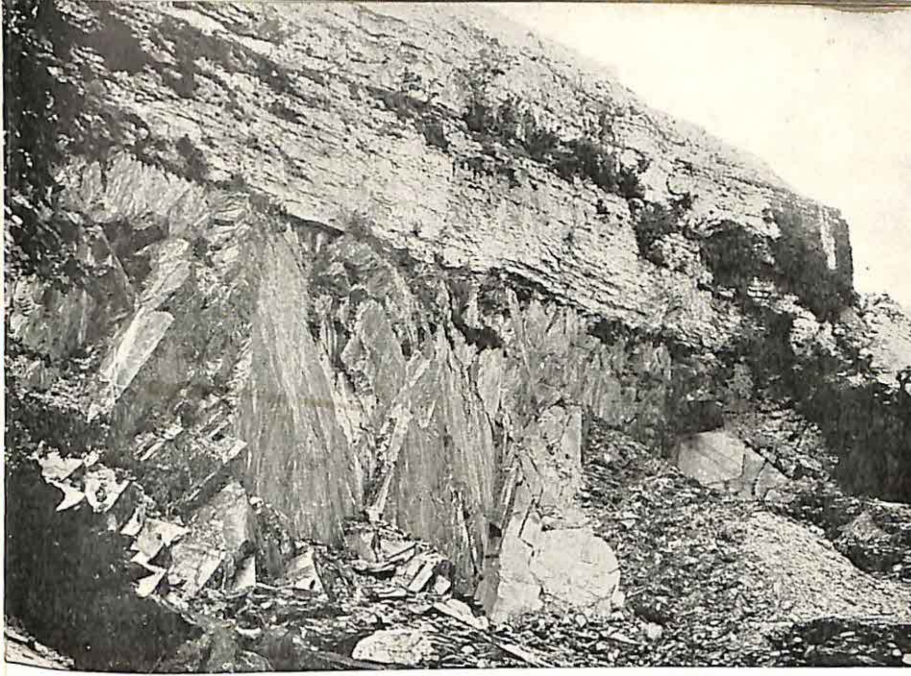


FIG. 94. Section through the Island of Barbados showing effect of slow rises in elevating coral reefs above sea level



[*Photo : British Association*

FIG. 95. An Unconformity. Horizontal Carboniferous Limestone resting on highly folded Silurian Slates

Settle, in the Pennines of northern England.

increases. This goes on until an unstable condition is reached and earth-building movements follow. Steady rising and falling of parts of the earth's crust are referred to as *eustatic* movements in contrast to *isostatic* or differential. Raised beaches, old sea-cliffs now far from the sea, and elevated coral reefs afford examples of a rising coast line ; submerged forests and the growth of some coral islands afford evidence of sinking coast lines.

CHAPTER VII

ROCKS AND MINERALS

Classification.—We have now considered the different ways in which the rocks of the earth's crust have been formed, and we are in a position to classify them. It is usual to distinguish five great groups :

(1) *Sedimentary Rocks*, those which have been laid down as sediments on land or under water and which therefore occur in beds or strata (stratified rocks).

(2) *Organic Rocks*, those which consist wholly or largely of the remains of organisms (animals or plants).

(3) *Chemically formed Rocks*, those which have been formed by chemical action.

(4) *Igneous Rocks* (Latin : *ignis*, fire), those which are connected in their origin with the heated lower layers of the earth's crust.

(5) *Metamorphic Rocks* (Greek : *meta*, change ; *morphe*, form), those which have been changed from their original character by heat or pressure. They may have originally been sedimentary, organic, or igneous.

Sedimentary Rocks.—We may classify sedimentary rocks either according to their *origin* or their *texture*, but usually both are taken into consideration. Thus according to origin we have :

(*a*) *Aeolian Deposits*, laid down on the surface of the land by wind—desert sand, dune sand, screes (which may be consolidated as breccias) loess, etc.

(*b*) *Riverine* (*Freshwater*) *Deposits*, laid down by rivers—gravels, sands, clays, alluvium, etc.

(*c*) *Lacustrine* (*Freshwater*) *Deposits*, laid down in lakes—gravels, sands, clays (especially grey and mottled pipe clays), etc.

(*d*) *Glacial Deposits*, laid down on land or sometimes under water by glaciers or on the melting of glaciers—moraines, boulder clays, glacial sands and gravels, erratic blocks, etc.

(*e*) *Marine Deposits*, laid down under the sea and linked with river deposits by *estuarine* or *brackish* water deposits, sometimes by *lagoon* deposits.

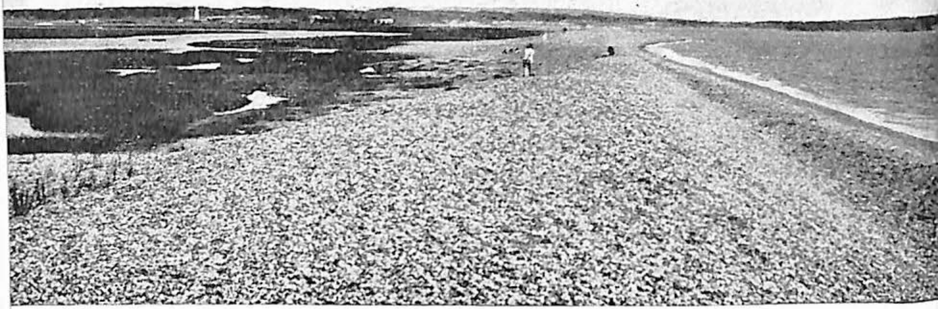
Groups (*a*) to (*d*) above, which are deposited on or near *continental masses* are sometimes grouped as *continental deposits*, as opposed to marine deposits. The origin of any particular rock cannot always be determined with ease. When *fossils* are present these form the best guide, when they are absent it is necessary to examine all evidence afforded by the rocks themselves.

Taking *texture* as the chief guide we may distinguish the following types of sedimentary rocks.

Breccia, a coarse rock consisting of angular fragments, sometimes originating as a scree and in any case of fragments which have not travelled far.

Gravel, a coarse deposit consisting of rounded stones usually in a matrix of finer material (sand, etc.). A gravel may have been laid down by a river (*e.g.* gravels of river terraces), in a lake, on land by a melting ice sheet (glacial gravels) or as a beach or shallow-water deposit by the sea. When a gravel is consolidated it forms a *conglomerate* or pudding stone.

Sand (Arenaceous rocks—Latin : *arena*, sand) is finer than gravel, but may have originated in many



[Photo : L. D. Stamp

FIG. 96. The Hurst Castle Shingle Spit, South England

This bank of beach gravel has been piled up by waves under the influence of the predominantly south-westerly wind (from the right) and encloses marshland on the left.

different ways. When consolidated it forms a *sandstone* and the matrix which binds the sand grains together may be of different minerals (usually deposited after the sand was laid down) by percolating waters. If the binding material is calcium carbonate (limestone) a calcareous sandstone results ; if an iron salt a ferruginous sandstone may be formed. If the material is silica (of the same composition as the sand grains) a very hard compact *quartzite* may result. Somewhat similar is *chert*. Sometimes the sand grains themselves afford a distinctive type as when many grains of felspar are included (felspathic sandstone or arkose) and some of the older sandstones are of a rough character for the same reason. Older sandstones with numerous other grains besides quartz are often called *greywacké*. Some sandstones include numerous flakes of the shiny mica so that they split easily even if quite hard. Sandstones which split easily are said to be fissile and may be used as flagstones (paving stones). The flakes of mica are flexible and occasionally the whole sandstone rock will bend under its own weight (flexible sandstone). *Grits* are sandstones composed of angular grains, though the name is sometimes used simply for a coarse sandstone.

Silt is finer than sand and often affords a transition to clay. Siltstones occur and some of the *marlstones* where the cementing material varies from lime to silica are really siltstones. Some types of alluvium are silt, some clay.

Clays (Argillaceous rocks—Latin : *argilla*, clay) are the most fine grained of all sediments, and it is often difficult to see the separate particles even under the most powerful microscope. Marine clays are usually dark grey or greyish-blue, but when exposed to the weather change to yellowish-brown. Estuarine and freshwater clays are often mottled yellow and red, or grey and red, or pale grey. Clays when wet are normally plastic; harder clays which are not plastic are called *mudstones*. When clays are hardened and show distinct bedding they become *shales*. Some clays can be heated to extremely high temperatures without melting; these are called fireclays. The word " marl " is loosely used for clayey rocks containing a proportion of lime, and for poorly consolidated limestones.

Till has already been described, but old or " fossil " tills occur and are called *tillites*. In some geological writings the term " boulder clay " is used as synonymous with till.

Organic Rocks.—Organic rocks form a much smaller group than sedimentary rocks. Like sedimentary rocks they usually occur in beds or strata and are, indeed, usually interbedded with sediments. The two main groups are:

(*a*) Those derived from the remains of animals.

(*b*) Those derived from the remains of plants.

Organic Rocks of Animal Origin include particularly many limestones. There are limestones such as *chalk* which consist partly of the hard parts or shells of foraminifera and other small organisms which live particularly in clear sea water. On their death the shells sink slowly to the floor of the sea. A great part of the substance of chalk, however, consists of finely divided calcium carbonate probably deposited chemically but as a result of the action of small organisms. *Ooze* is the modern equivalent of chalk. Other limestones consist of molluscan shells (which may have drifted and have been broken up and hence could be regarded as sedimentary rocks). Others consist mainly of *coral* (coral rock and coral limestone). Old coral reefs are found in many parts of the world, and many limestones are built up mainly of remains of coral. At the present day the coral polyp can only live in warm seas in shallow water, and so the growth of coral islands (as in the Pacific) is held to prove continued subsidence, the coral growing steadily upwards. An old British name for a limestone of broken fragments is *rag* (coral-rag, etc.) or locally *crag* (Coralline crag, etc.). All these limestones consist essentially of calcium carbonate ($CaCO_3$). The majority are of marine origin but freshwater limestones may occur. Magnesian limestone, sometimes rather mistakenly called dolomite, contains a proportion of magnesium carbonate ($MgCO_3$). True dolomite is a mineral with a precise formula—a carbonate of calcium and magnesium.

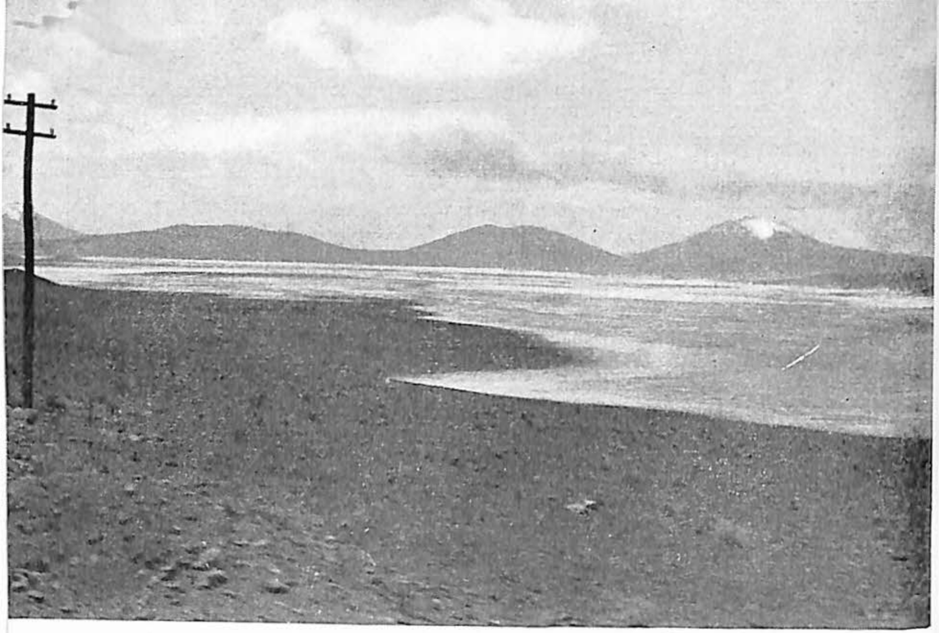
Some tiny creatures, including also the plants known as diatoms, have skeletons or hard parts built up of silica (SiO_2) and so give rise to organic rocks of siliceous character. Many *cherts* are of this origin including radiolarian cherts. Radiolaria are minute animals allied to foraminifera. Another source of silica is the spicules of siliceous sponges.

Some organic rocks consisting largely of calcium phosphate have been derived from bones of fish (*bonebeds*); others are derived from droppings of animals and birds (*guano*, *coprolites*, etc.).

Organic Rocks of Vegetable Origin comprise rocks derived from drifted masses of vegetation and also rocks derived from moss, trees, etc., which have been buried where they grew. *Peat* shows the structure of the original wood or plant structure; in *Lignite* or *Brown Coal* this has largely disappeared. In true *Coal* all traces of vegetable structure have normally disappeared. *Anthracite* is a hard, compact coal with a high proportion of carbon. Some beds of *carbon* (graphite or blacklead of pencils) in ancient rocks may originally have been vegetable remains. All these are called carbonaceous rocks. All plants consist largely of compounds of carbon with the gases hydrogen, oxygen, nitrogen, etc., with large quantities of water and small proportions of mineral salts. When the plant substance is converted into coal the gaseous materials, and the water, are gradually eliminated so that peat has some 60 per cent. of carbon, anthracite over 95 per cent.

Under other conditions vegetable material may be converted into *mineral oil*.

Chemically-Formed Rocks.—These constitute a small class and consist chiefly of rocks formed by the evaporation of water which had various substances



[Photo: L. D. Stamp

FIG. 97. A Dried Lake Bed in the Atacama Desert of Northern Chile, now with a white deposit of borax

Notice the snow-covered extinct volcano of the Andes

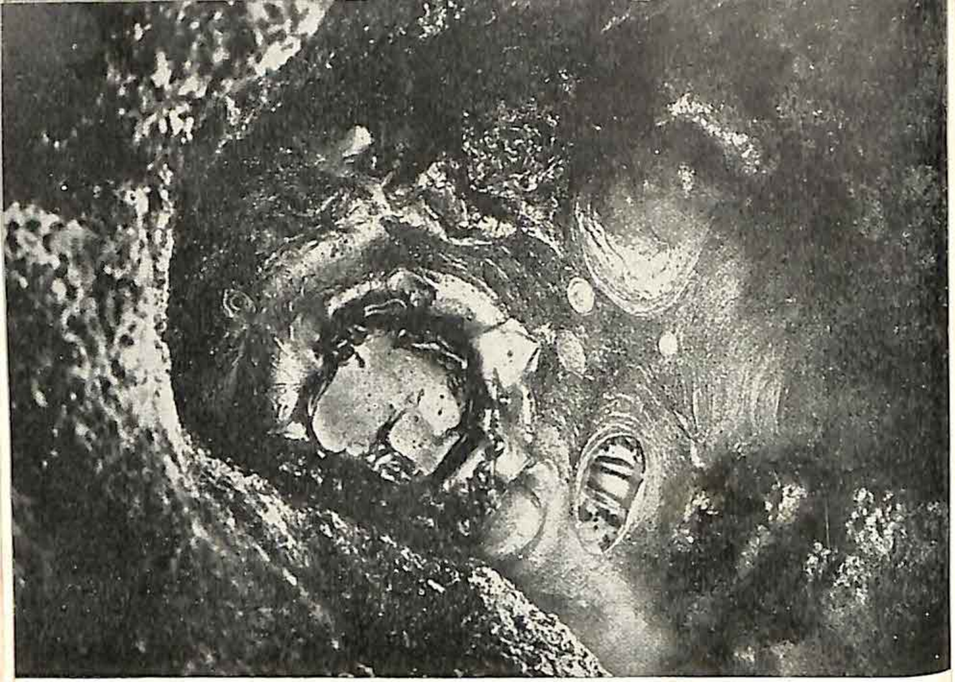
in solution. Beds of *salt*, *nitrate*, *borax*, etc., naturally result when desert lakes dry up, but many limestones belong to this group also. There are the deposits of *stalagmite* formed on the floors of caves, or the *stalactites* which hang from the roof. In both cases water charged with carbon dioxide has dissolved limestone and then, when the drops of water evaporate, the calcium carbonate is left behind in crystalline form. Limestone, known as calcareous tufa, may be deposited by springs. Similarly limestone is chemically deposited in lakes and clear seas, in the latter case often as tiny grains round nuclei producing an *oolite* (Greek: *oon*, an egg, in this case suggested by the minute eggs in a fish roe) or, if the grains are larger, *pisolite*. It is often difficult to separate chemically and organically formed rocks because of the action of organisms (*e.g*. algæ) in causing chemical depositions and then leaving no trace of their existence. In addition to the existence of chemically formed rocks, the chemical deposition of material in sedimentary rocks often cements together the particles (*cementation*) and alters their character.

It may be claimed that those rocks resulting from the chemical action of weathering also belong to this class. A good example is clay-with-flints which occurs locally capping the chalk of England and France and which represents the insoluble residue after the chalk (calcium carbonate) has been removed in solution.

Igneous Rocks.—According to their mode of occurrence three main groups of igneous rocks may be distinguished:

(*a*) *Volcanic Rocks*.—Those which have been poured out on the surface. Naturally they cooled comparatively quickly, sometimes so quickly that there was not time for crystals to form, and the resulting rock is glassy (*obsidian*, *tachylite*, with a frothy surface of *pumice*). In any case any crystals which formed had but a limited time to grow and the result is a fine-grained rock. A very common example is the lava *basalt*.

(*b*) *Hypabyssal Rocks*.—Those which solidified a short distance underground as dykes, sills, laccolites, etc. These cooled more slowly and are usually entirely crystalline though the crystals are small. A good example is *dolerite* which is the same as basalt except for the different crystalline texture. Sometimes there are large crystals (porphyritic crystals)



[*Photo : Aerofilms*

FIG. 98. An Aerial View of the Crater of Mount Vesuvius showing the Liquid Lava

in a fine-grained ground mass. This is the case with the rock porphyry.

(*c*) *Plutonic Rocks* (Greek : *Pluto*, the god of the underworld).—Those which solidified as great masses far down in the earth's crust and have only been exposed at the surface as a result of long continued denudation. They cooled very slowly and are usually coarsely crystalline. Sometimes the crystals may be several inches in length. A good example is *granite*.

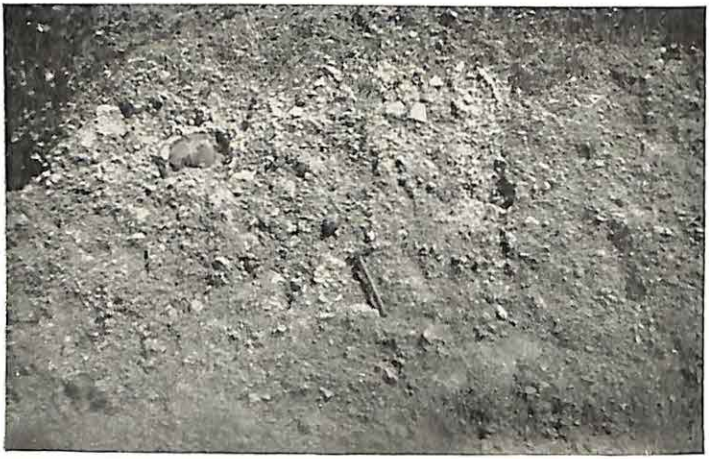
According to their chemical composition some igneous rocks have a large proportion of silica (SiO_2) and these used to be called (somewhat mistakenly) " acid " rocks. Some of the silica combines with other constituents to form silicates such as felspar, mica, etc., but there is still some silica left over and this crystallizes to form quartz. So this group of rocks has free quartz among their crystalline constituents. They are over-saturated with quartz.

Other igneous rocks are intermediate in character but only rarely have free quartz.

Others which used to be called " basic " have not sufficient quartz to form the usual silicates, and which in consequence have dark coloured minerals such as *augite*, *hornblende*, *olivine*, and *dark mica* in abundance, and consequently the rocks are usually dark in colour. A modern name for this group is under-saturated because the molten rock or magma is more than fully supplied with the dark constituents and is deficient or under-saturated in silica. There are also the "ultra-basic" rocks in which there is still less silicia—not enough to form the usual silicate minerals.

The following table shows a simple classification of igneous rocks with the names of some of the chief rocks.

Rock-Group	Over-Saturated	Intermediate or Saturated	Under-Saturated
Volcanic	Pumice (froth) Obsidian (glass) Rhyolite	Trachyte Andesite	Basalt
Hypabyssal or Dyke	Felsite Microgranite Quartz porphyry	Porphyry	Dolerite
Plutonic	Granite	Syenite Diorite	Gabbro, Serpentine



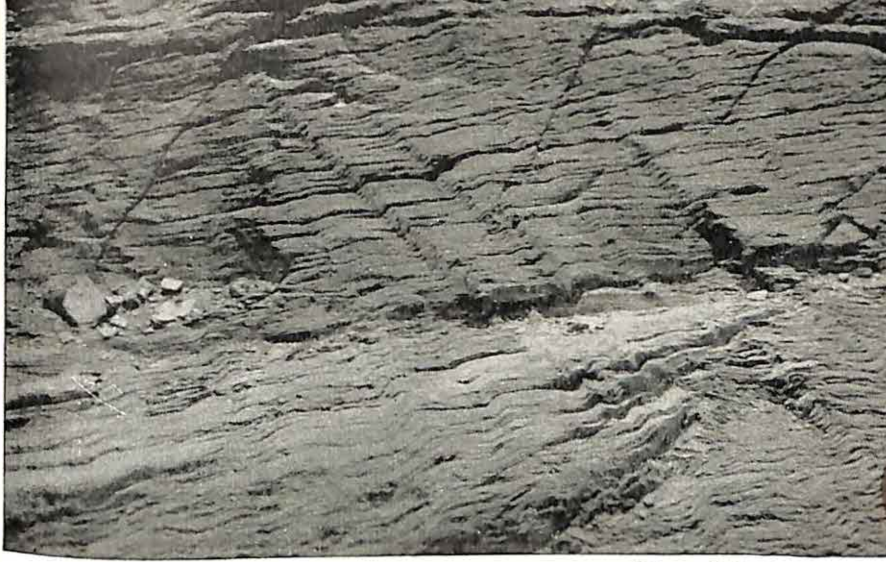
[Photo: L. D. Stamp

FIG. 99. A Bed of Volcanic Ashes with large Rounded Bombs

Mt. Popa, Burma.

The explosive action of volcanoes produces a whole group of *volcanic ashes* which vary greatly in composition. If the rock has many large angular fragments it is called an agglomerate. A consolidated ash rock is called a tuff.

Metamorphic Rocks.—Two changes in particular take place when rocks are changed by pressure (through folding in mountain-building movements) or by heat (through being near igneous rocks or by being folded far into the lower hot layers of the crust). At first the rocks are hardened, and then they are completely changed by being re-crystallized. Amongst the changes caused by pressure is the development of *slaty cleavage*. Minute crystals of mica become arranged with their flakes at right angles



[*Photo: L. D. Stamp*

FIG. 100. A Metamorphic Rock—Foliated and Contorted Slates
Newquay, South-west England.

to the direction of pressure and so the rock naturally splits in this new direction. The chemical composition of the whole rock may remain the same but in texture and appearance it is completely changed. The development of a crystalline structure often causes a marked resemblance to igneous rocks. Thus a gneiss is very similar to a granite except that the rock is *foliated* to accord with the bedding of the original rock. All rocks may be metamorphosed—sedimentary rocks, organic rocks, chemically formed rocks, and igneous rocks—and it is often difficult to tell what was the character of the original. Some of the better known changes are as follow:

Pure sands and sandstones become hard quartzites.
Clays and shales become slates, killas, and schists (especially mica-schists).

Limestones become crystalline marbles.
Granites become foliated and streaky, and are converted into gneisses.

Since metamorphic and igneous rocks are both normally crystalline they are often grouped together as *Crystalline Rocks* and tend to occur in large tracts (the ancient stable blocks) of the earth's surface.

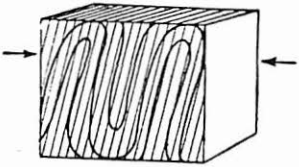
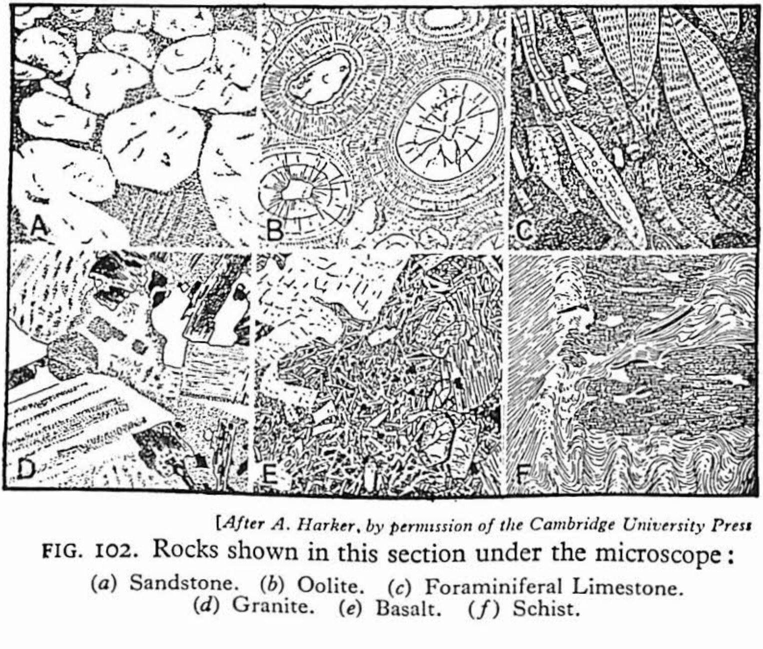


FIG. 101. Slaty Cleavage

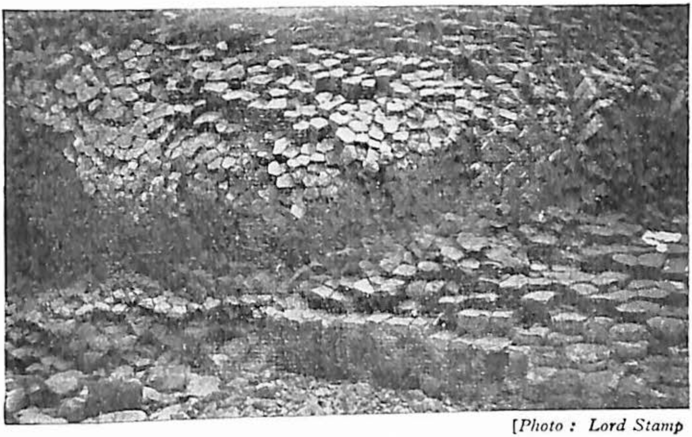
The study of rocks (Petrology—Greek : *petros*, a rock) is an important and extensive study of its own. Rocks are examined by means of thin sections under the microscope, and the minerals are identified by means of their appearance in this form.



[*After A. Harker, by permission of the Cambridge University Press*

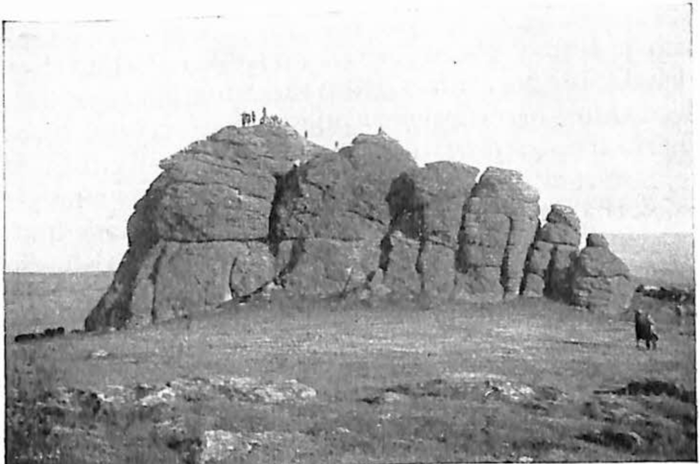
FIG. 102. Rocks shown in this section under the microscope:

(*a*) Sandstone. (*b*) Oolite. (*c*) Foraminiferal Limestone. (*d*) Granite. (*e*) Basalt. (*f*) Schist.



[*Photo : Lord Stamp*

FIG. 103. Island of Staffa, Western Isles of Scotland, built up of Basalt Lava which in cooling has formed hexagonal columns



[*Photo : L. D. Stamp*

FIG. 104. A Granite tor, South-west England. Weathered Granite

Minerals.—There are very large numbers of chemical compounds which occur naturally in the earth's crust. They are distinguished from one another not only in chemical composition but also in their physical characteristics—colour, hardness, form, etc. The majority of minerals, if they have been allowed to form slowly from the cooling of a molten mass or from the evaporation of the water of a solution, naturally form crystals. So the crystal form is highly characteristic and even if the whole crystal form does not develop the mineral shows lines of cracking or cleavage peculiar to its crystal form. There are six great crystal systems: (*a*) cubic, in which a common form is the cube; (*b*) tetragonal, in which the simplest form is like a cube, but elongated; (*c*) orthorhombic; (*d*) hexagonal, in which the commonest forms are six-sided columns or six-sided pyramids; (*e*) monoclinic; and (*f*) triclinic.

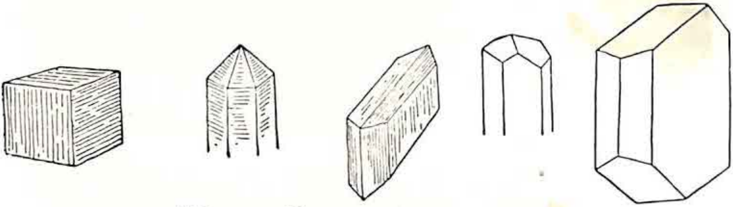


FIG. 105. Common Crystal Forms

Cube (Iron Pyrites FeS_2)

Hexagonal Prism and Pyramid (Quartz SiO_2)

Monoclinic (Gypsum $CaSO_4$ $7H_2O$)

Othorhombic (Calcite Nail Head Spar $CaCO_3$)

Triclinic (Felspar

Of the innumerable minerals which exist, it is important to know some of the chief *rock-forming* minerals, and also some of those which, though much less abundant in nature, are important as the sources of the metals required by man. Some minerals are *stable*, that is to say when they are washed out of their original rocks by weathering and other processes they are broken up into small pieces, but remain the same. Other minerals are *unstable*; when the rock which contains them is weathered these minerals are changed chemically (just as when iron rusts and ceases to be iron, being changed to red rust or iron oxide—indeed, iron is so unstable that it is almost unknown in nature) and so disappear. Naturally, sands consist only of stable minerals.

Rock Forming Minerals.—Of these *quartz* (silicon dioxide or SiO_2) is one of the more important. When pure it is hard, colourless and transparent (like a hard glass) and occurs in hexagonal crystals. It is very stable, and although only occurring in limited amounts in granites, gneisses and other crystalline rocks it forms the bulk of the grains in most sandstones and silts. Besides quartz, there are other forms of silicon dioxide which are slowly soluble by water. When deposited from solution they may form a cementing material and so change a soft rock into a hard one. *Felspars* are complex silicates of sodium, potassium, lime, and aluminum occurring in most crystalline rocks but not very stable when washed out. *White mica* (stable) and *dark mica* or biotite (less stable) are also complex silicates and form the shiny six-sided flakes so common in many rocks. *Augite*, *Hornblende* and *Olivine* are complex silicates of iron, magnesium, calcium, and aluminum which are found in most dark-coloured igneous and many metamorphic rocks but which are unstable and rarely found in sedimentary rocks. *Calcite* ($CaCO_3$) is the pure form of limestone and when pure is colourless like quartz but is soft and easily breaks up into little rhombs. In various impure forms it forms the great masses of limestone. It may grade into a carbonate of lime and magnesium(*Magnesian Limestone* & *Dolomite*). *Clays* are very complex silicates and form the final products in the weathering of many different minerals, such as the felspars. The crystals of clay are so tiny that their existence was long doubted.

Many rocks have brownish or red colours. These colours are usually due to small quantities of compounds of iron. If the compounds of iron are found in sufficient quantity the rock becomes an *iron ore*.

Metallic Minerals.—A large number of the minerals which are important because they contain the metals desired by man occur in *veins*. *Gold* usually occurs native, *i.e.* as small specks or particles of pure gold. Gold is very stable, so grains of

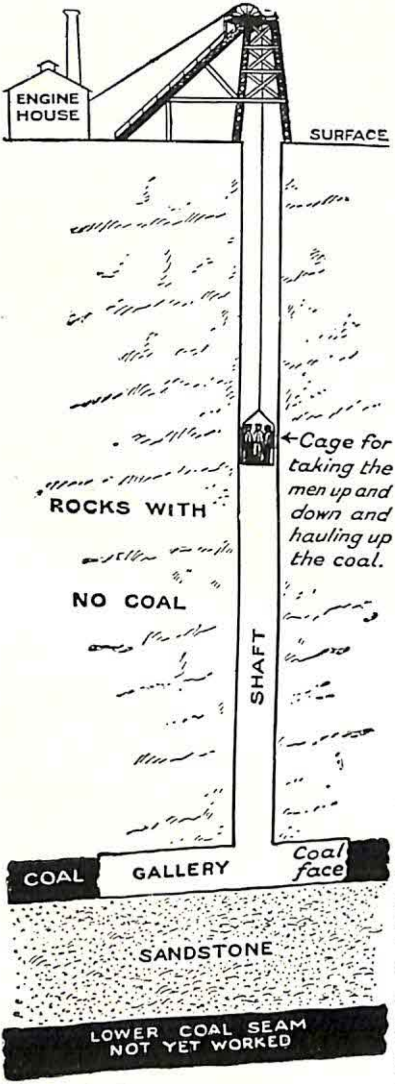

ENGINE HOUSE
SURFACE
ROCKS WITH
NO COAL
SHAFT
←Cage for taking the men up and down and hauling up the coal.
Coal face
COAL
GALLERY
SANDSTONE
LOWER COAL SEAM NOT YET WORKED

FIG. 106. Section through a Coal Mine

gold are found in sands (*alluvial gold*). *Tin* occurs mainly as tin oxide (*cassiterite*) also very stable and so found both in veins and in alluvial deposits. *Lead* occurs especially as the unstable sulphide *galena* (PbS_2) which often contains *silver* as an impurity (this is a leading source of silver). Zinc also occurs as an unstable sulphide, *zinc blende* (ZnS). Copper is found in more varied forms—native, as blue and green carbonates, and as a sulphide mixed with iron (*copper pyrites*, $CuFeS_2$). *Iron* is found very widespread in nature. The purest ores are *magnetite* or magnetic iron oxide (Fe_3O_4) and *hæmatite* or red iron oxide (Fe_2O_3) but many *brown iron ores* (oxides with varying proportions of water combined chemically) occur and also iron carbonate. Magnetite and hæmatite are associated especially with igneous rocks, or with chemically deposited rocks but the brown ores are often ordinary sedimentary rocks (*marlstone*, etc.). The sulphide (iron pyrites, FeS_2) is more important as a source of sulphur than of iron. It occurs in brassy-looking cubes.

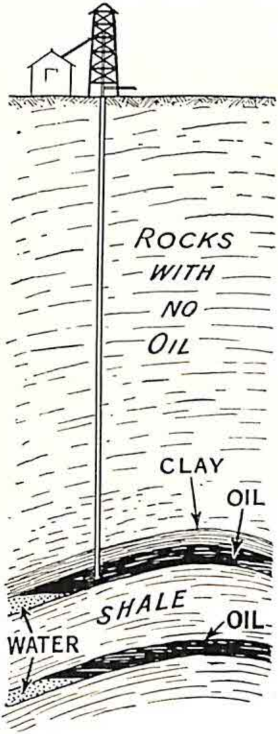
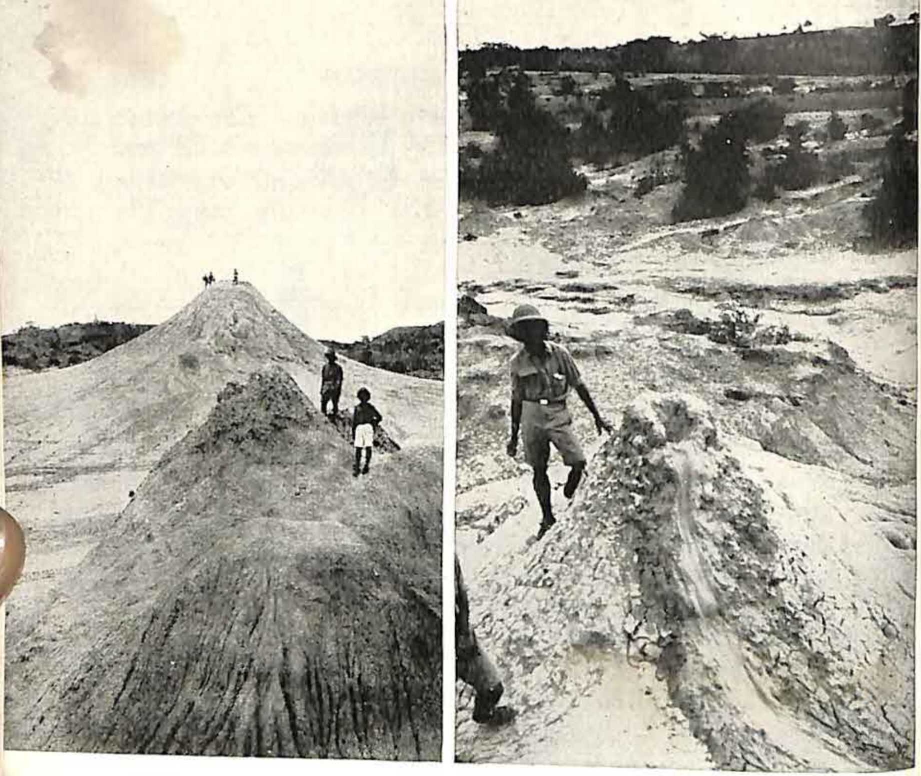


FIG. 107. Section through an Oilfield

Rocks of Economic Importance.—Many different rocks are used as *road-metal* provided they are conveniently situated, hard but tough (*i.e.* do not



[Photo. : L. D. Stamp

FIGS. 108 and 109. The famous Mud Volcanoes of Minbu, Burma

Liquid mud is forced up by the movement of gas associated with an oil field.

splinter too easily) and so particularly granites, dolerites, and basalts are valued. Amongst *building stones* are granites, limestones (especially the oolitic limestone which freely splits in all directions and so is known as freestone) and sandstones. Chalk and other limestones are burnt for *lime* and for the making of *cement*. The origin of *coal* has already been described and coal seams occur interbedded with sandstones and shales. The mode of occurrence of *oil* is clear from the diagram, Fig. 107. *Clays* vary greatly in character and their economic uses vary accordingly. Pure white *china clay* is needed for the manufacture of china and porcelain, grey *pipeclay* for pottery, grey *fire clay* for bricks which will resist heat (firebricks) but many ordinary clays can be used for coarse pottery and earthenware, such as drainpipes, and for bricks.

Rock-salt ($NaCl$) is often found in beds amongst sedimentary rocks, so also is *gypsum* ($CaSO_4$, used in the manufacture of plaster of Paris) though this is also found as small crystals in clay. *Fluorite* (CaF_2) forms cubes more often found in mineral veins.

CHAPTER VIII

THE ATMOSPHERE—WEATHER AND CLIMATE

Composition of the Atmosphere.—Surrounding the earth's crust is that envelope of invisible colourless gases which we call the air or atmosphere. The air consists chiefly of the following gases :

Oxygen	21 per cent,
Nitrogen	78 ,,
Argon and Neon	1 ,,
Carbon dioxide	0·02 ,, (varies)
Water vapour	Variable quantity

Oxygen is the gas which is necessary to support life ; it is breathed in by animals and plants in the process of *respiration*, part being absorbed, part being converted to carbon dioxide and breathed out both by animals and plants. Thus "stale air" such as that in a closed room with many people has a high proportion of carbon dioxide. Under the influence of sunlight and the green colouring matter chlorophyll, plants take in carbon dioxide and, combining it with water and mineral salts derived from the soil, convert it into plant substance. In this process of *assimilation* oxygen is given out. Argon and neon are inert gases and so too is nitrogen which in the main simply dilutes the oxygen. There are some bacteria, living in the root nodules of plants belonging to the Pea and Bean Family (Leguminoseæ) which are able to use the nitrogen of the atmosphere in the manufacture of nitrogenous plant foods.

Pressure of the Atmosphere.—The air, being a mixture of gases, is compressible and the lower layers are denser than the upper layers where the air is rarefied. The upper layers, attracted towards the centre of the earth by gravity, press down on the lower layers. Near sea-level the pressure of the air is normally sufficient to balance a column of the heavy liquid metal, mercury, 30 inches high. This is the principle of the *barometer* (Greek: *baros*, weight, metron, a measure) and the pressure of the atmosphere is frequently stated as so many inches—*i.e.* equivalent to so many inches of mercury. As we ascend the pressure becomes much less. On the top of Mt. Blanc, the highest mountain in Europe (15,000 feet) it is about 15 inches; at a height of 30,000 feet it is about 6 or 8 inches. It is difficult to determine the exact height of the atmosphere but there is sufficient oxygen to kindle meteorites at a height of 50 miles though clouds rarely occur above 6 miles. Air pressure is also measured in units of the metric system. A pressure of 1,000 millibars is about equal to 30 inches.

Air when heated expands and rises: hot air is lighter than cold air. Warm air is able to absorb more water vapour than cold air. Curiously enough damp air—air with much water vapour—is lighter than dry air. So warm damp air always tends to rise, cold dry air to descend.

Temperature of the Atmosphere.—The air derives its heat to a small extent from the sun's rays passing through it, but much more from the re-radiation of solar heat from the surface of the ground or water. At high levels where the air is thin it is thus very cold, though the sun's rays strike fiercely on the ground the heat is quickly lost at night because there is little air to act as a blanket. The diagram shows the reason for the greater heat received at the equator, where a bundle of sun's rays are spread over a small surface which they strike almost vertically, than at the poles where the same bundle of sun's rays are spread over a much greater area and have passed through a greater thickness of air and so have lost more heat.

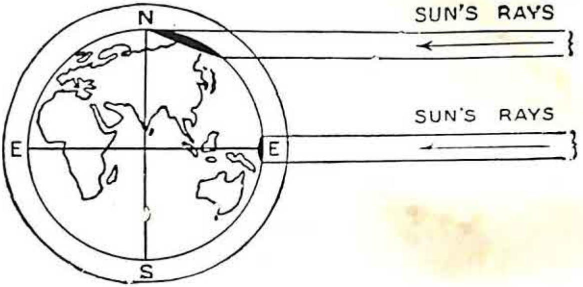


FIG. 110.

So the temperature of the air varies from hour to hour, day to day, and month to month.

The temperature is measured by the *thermometer* and in normal practice it is measured *in the shade*, at a height of 5 feet from the ground. Maximum and minimum thermometers are used, and these record the highest and lowest—the difference between the two is the daily range, the difference between temperatures reached during the day of 24 hours. The mean daily maximum temperature for a month is the average of the daily maximum readings; the mean daily minimum temperature for a month is the average of the daily minimum readings. The mean of these two figures is the mean daily temperature for the month. The difference between the mean of the hottest month and the mean of the coldest month is the *annual range*.

Variations in Temperature.—Temperature varies from hour to hour, day to day, and month to month, but there are certain major variations.

(*a*) Temperature varies with distance from the equator to the poles for reasons mentioned on p. 118.

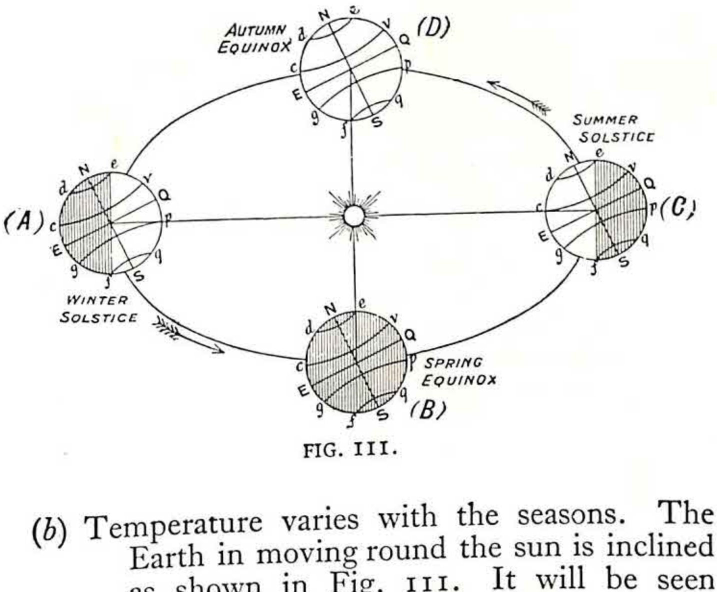


FIG. 111.

(*b*) Temperature varies with the seasons. The Earth in moving round the sun is inclined as shown in Fig. 111. It will be seen from this diagram that on June 21st (the Summer Solstice of the Northern Hemisphere) the sun is shining vertically over the Northern Tropic (Tropic of Cancer, $23\frac{1}{2}$° N.). On December 22nd (the Winter Solstice of the Northern Hemisphere) the sun is shining vertically over the Southern Tropic (Tropic of Capricorn, 23½° S.).

(*c*) Temperature varies with the distribution of land and sea. Land becomes heated more rapidly than a great body of water, but also loses or radiates its heat more rapidly. So the great continental interiors become very hot in the hot season, very cold in the cold season. The heart of Asia is a good example.

The Planetary or Regular Winds.—If we could imagine the Earth's surface uniformly covered with a layer of water of uniform depth, there would be no interference with the regular heating of the air. We should expect a belt of hot and moist air round the equator. Hot, moist air being light this would rise, and cooler, heavier air from north and south would pour in to take its place. Owing to the rotation of the earth these winds would be from the north-east in the northern hemisphere and from the south-east in the southern hemisphere. Actually we do find such winds—the *Trade Winds*—over the sub-tropical oceans.

There they are regular and constant in strength and direction; over the land they are less regular and may be absent. The position of the Trade Wind belts varies with the seasons. During the northern summer or hot season, that is, in June and July, when the sun is shining vertically over the Tropic of Cancer (north of the equator) the low pressure belt of the equatorial region is rather north of its average position, and so at this season of the year the Trade Winds are blowing farther north than is the case at other seasons. Similarly, in our winter in December and the months near, these winds are south of their average position. The Trade Winds thus blow mainly within the Tropics and are especially noteworthy over the sea and on lands adjoining the sea. Notice that they blow in each case from eastern points, so that they are felt on those lands which are on the eastern sides of the great continents in equatorial regions—along the east coasts of America and of Africa, Asia and Australia.

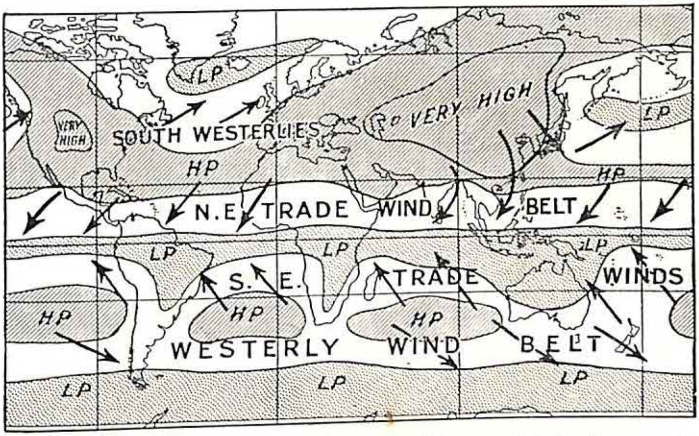


FIG. 112. The regular Wind Belts of the world (in January)

Then in the Temperate Zones the winds blow not nearly so regularly but usually from the west, and we call these winds therefore the "*Westerlies.*" In the Northern Hemisphere we have the south-west winds, or South-west Anti-trades as they are sometimes called. In the Southern Hemisphere they blow from the north-west. Notice from a map of the world, or from the globe, that in the South Temperate Zone there is a tremendous amount of sea, and so over this sea we find the winds blowing very regularly; but in the Northern Hemisphere are the great land masses, and so the south-westerly winds are much less regular. British Columbia like Britain lies within the belt of these winds, and so there the most important winds do blow from the south-west.

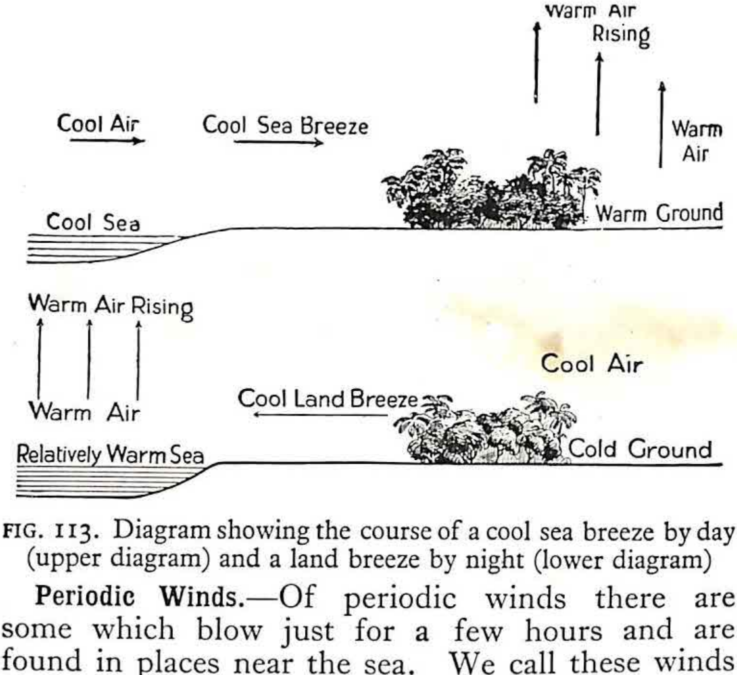


FIG. 113. Diagram showing the course of a cool sea breeze by day (upper diagram) and a land breeze by night (lower diagram)

Periodic Winds.—Of periodic winds there are some which blow just for a few hours and are found in places near the sea. We call these winds land and sea breezes. For during the day the land becomes heated up more quickly than the sea. The air over the land is therefore heated too and becomes light and rises. A cool sea breeze blows in from the sea, because this is the cool air blowing in to take the place of the warm air which has risen over the land. Many places on the sea coast would be very hot indeed if it were not for this cooling breeze from the sea. But during the night the land cools more rapidly than the sea, and for some hours after sunset the air over the land is colder than over the sea; with the result that the cold, heavy air from the land flows out to the sea as a land breeze.

Monsoons.—A great mass of land, such as a continent, becomes greatly heated during the summer, and the air over it becomes hot and rises so that cooler air is likely to blow in from the ocean to take its place. This is not unlike the sea breeze just explained, except that instead of blowing for a few hours the cool wind from the ocean blows for the hot half of the year, possibly for six months. Such a wind is called a monsoon. In the winter the continental mass becomes very cold, and so the cold, heavy air over it blows outwards to the sea, and there are outblowing cold winds at this season. The largest land mass in the world is Asia and the monsoon winds are most important round the continent of Asia, especially in the south-east

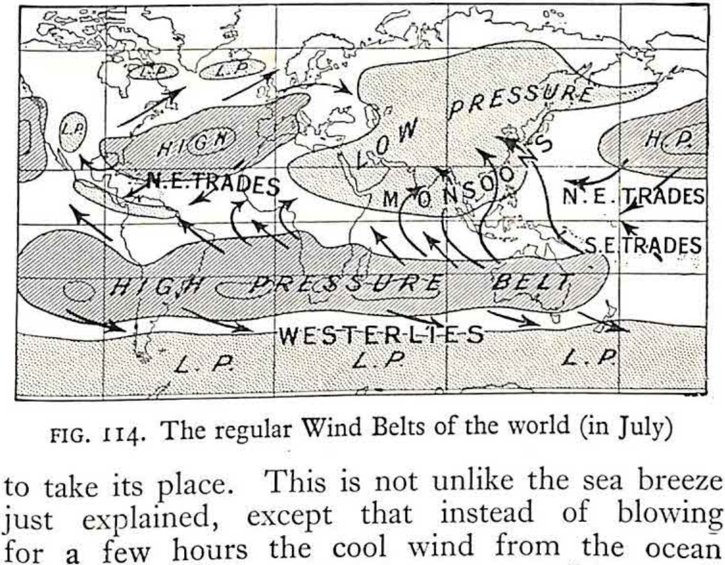


FIG. 114. The regular Wind Belts of the world (in July)

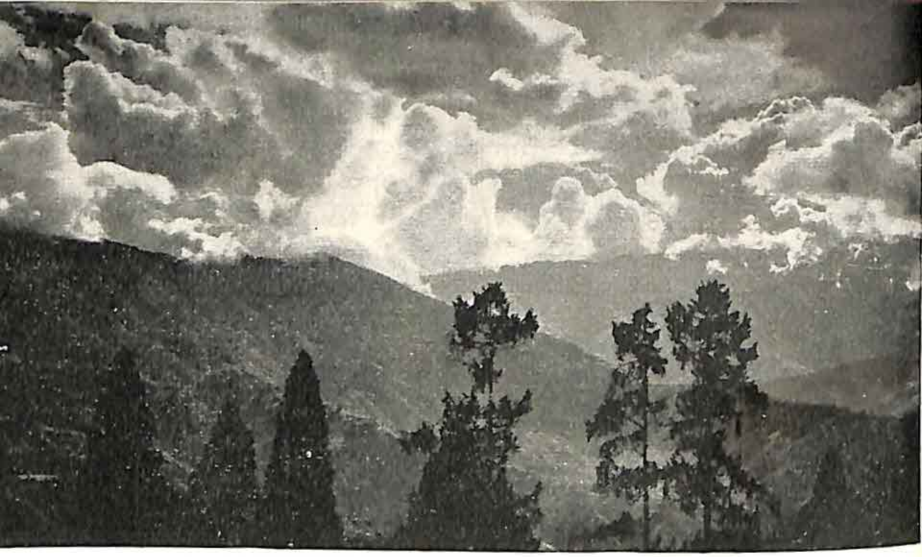
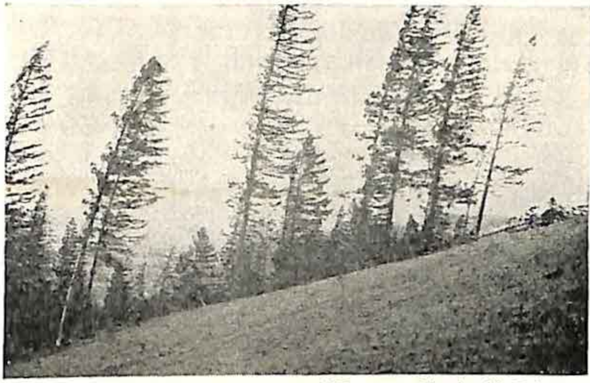


FIG. 115. Clouds blowing up from the Bay of Bengal and the Himalayas during the summer Monsoon

and east. This is clear from the pressure belts and the wind systems of the world shown in Fig. 114.

Temporary Winds.—Of the *temporary winds* the most important are those which are associated with cyclones or depressions and anti-cyclones. In all parts of the world, but especially in temperate regions, there are local areas of high pressure surrounded by regions of low pressure, or small regions of low pressure in a belt of high pressure. Naturally the winds tend to blow towards the centre of a low pressure system or depression ; but actually they are deflected to the right by the rotation of the earth's surface (to the left in the southern hemisphere). Above the ground they blow along the " isobars," or lines of equal pressure. At ground level, however, they are slowed down by friction, and tend to spiral inwards towards the centre of the " low " in a counter-



[Courtesy: Zwolenski, Zakopane

FIG. 116. Trees during the blowing of the Fohn winds, Zakopane, Carpathians, Poland

clockwise sense (clockwise in the southern hemisphere). An anti-cyclone usually brings fine weather, sometimes very cold in winter; the winds blow round and away from the centre in the same direction as the hands of a watch, that is, in a clockwise direction. These great eddies and whirls in the main current of the air, especially in the belt of the westerly winds, are like the eddies or the whirls in a stream or a river which is in general flowing on its way towards the sea. Cyclones or depressions with inblowing winds usually bring wet, stormy weather, cool in summer, but mild in winter.

In many parts of the world there are local winds of special importance because of their strength or special character. Amongst these are the warm mountain winds (fohn or chinook winds); the hot dry desert winds (simoon, sirocco, harmattan) often dust laden, and the cold mountain winds (puna of the Andes and mistral of Provence, France).

Rainfall.—When saturated air, or moisture-laden air, is cooled condensation takes place, and so rainfall, or if it is cold snowfall, results. The word precipitation covers both rainfall and snowfall.

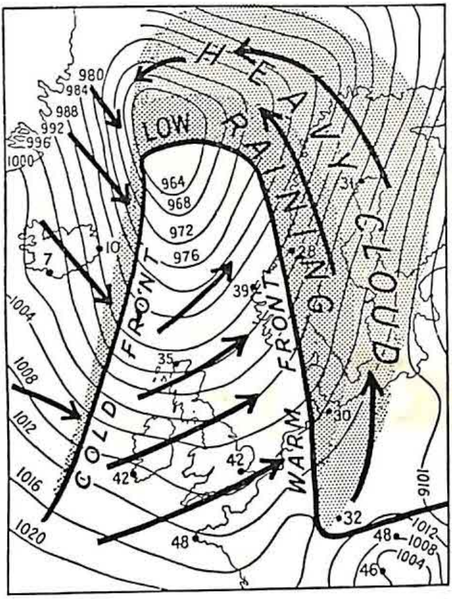


FIG. 117. A Cyclone over the British Isles.

The fine lines are lines of equal pressure; the figures, such as 32, etc., are temperatures; the arrows show wind.

Care should be taken to distinguish between *observed* details and the interpretation of them. The figures of temperature and pressure, the existence of heavy cloud and the area where rain is falling as well as wind directions are all *observed* conditions. The isobars which have been drawn are an interpretation of the observed pressures; the positions of the "Warm Front" and the "Cold Front" are inserted as an interpretation of the general conditions based on what is now called the Polar Front hypothesis. This hypothesis presumes that cyclones are caused by friction between warm air moving from the south-west against the front of a relatively stagnant mass of cold air round the pole. The junction between the two main masses of air is marked by the heavy line.

The air obtains its moisture by evaporation from the surfaces of large areas of water such as the ocean or from forested land-areas, which provide much moisture by the *transpiration* of the trees. Air which has come from dry land regions is usually dry.

There are several ways in which moisture-laden air can be cooled enough to condense out the moisture as cloud, and sometimes as rain or snow. The really important sources of rain all involve a bodily uplift of the air. This is achieved in three different ways:

(1) **Convectional Uplift,** in which heated air rises, cools, and becomes a large cumulus cloud, like the head of a cauliflower in form. Sometimes heavy rain-showers are started in this way, and thunderstorms are common. Naturally this kind of rain is most frequent in the Tropics, but it can happen in temperate latitudes when a hot sun beats down on a land-surface, or when cool air passes over a warm sea.

(2) **Geographic Uplift,** where moist air is forced to rise over a mountain. Cloud, and often rain or snow, form over the windward slopes and the summit (see below).

(3) **Cyclonic Uplift,** in which moist, warm air is forced to rise within a travelling low-pressure system. Most of this uplift is due to the sliding up of warm air over the gently-sloping surface of a cooler airmass along the *fronts* of the cyclone. See fig. 117.

When a moisture-laden wind is forced to rise over a mountain range it must be cooled and is sure to lose some of its moisture. The higher the mountains, the more moisture is lost. When the wind has finally passed over the range it is almost a dry wind; further, when the wind drops to the lower ground it is warmed by compression, so it becomes a thirsty wind and not one which is ready to shed any of its moisture. That side of a mountain range which faces the rain-bearing wind and receives the rain we call the windward side ; the dry side we call the lee side, or leeward side. The land which is kept dry in this way by a mountain range is said to be in the "rain shadow" of the mountains. The rains which fall on the lee side are mainly convectional or cyclonic rains. Just as in Europe the rainy west of England has over 100 inches a year in the Lake District whilst the dry east coast has less than 25, so in North America western Vancouver Island has over 100 inches against Victoria's 27 inches. Similarly, a large part of the plateau of India is in the rain shadow of the Western Ghats, and so receives very little rain.

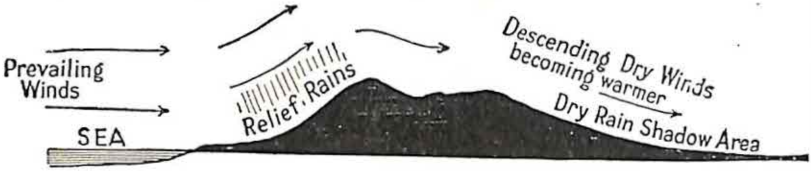


FIG. 118. Rain Shadow Area

Rainfall is measured by means of a rain-gauge. All the rain which falls over a certain area passes into a funnel and is collected into a jar where it cannot evaporate, and where it can be measured.

In those countries where all or part of the precipitation is in the form of snow a somewhat different method of measurement has to be adopted. But the snow which falls is calculated in terms of water. Roughly a foot of snow is equivalent to an inch of rain. In addition to rain and snow, precipitation may take the form of drizzle, hail and sleet. Precipitation direct on to the ground forms dew and, when frozen, hoar-frost or rime.

When we say that the rainfall for one day has been 2 inches, we mean that if all the rain which fell that day had remained where it fell, it would have formed a layer 2 inches deep. In nature, as soon as the rain falls, some of it sinks into the ground and becomes "ground water," some of it evaporates, and some runs into the streams and rivers. Rainfall is recorded for each day, and then by *adding* up the amounts for each day the monthly amounts are obtained. The most important figures are the *monthly averages*.

Rainfall Maps.—On a map of any country we can mark the monthly or yearly averages. Sometimes it is better to use the amount for a season, such as the rainy season. On any rainfall map lines drawn through places having the same rainfall are called "isohyets." Rainfall changes gradually; there can scarcely be one region with a rainfall of more than 80 inches, and the next region less than 40. There must be an area between, even if it is only a narrow strip, having a rainfall from 40 to 80 inches.

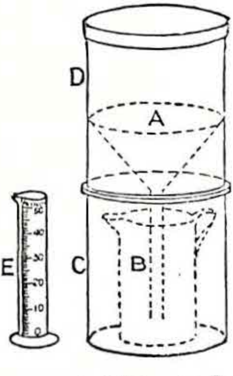


FIG. 119. Picture of a rain-gauge

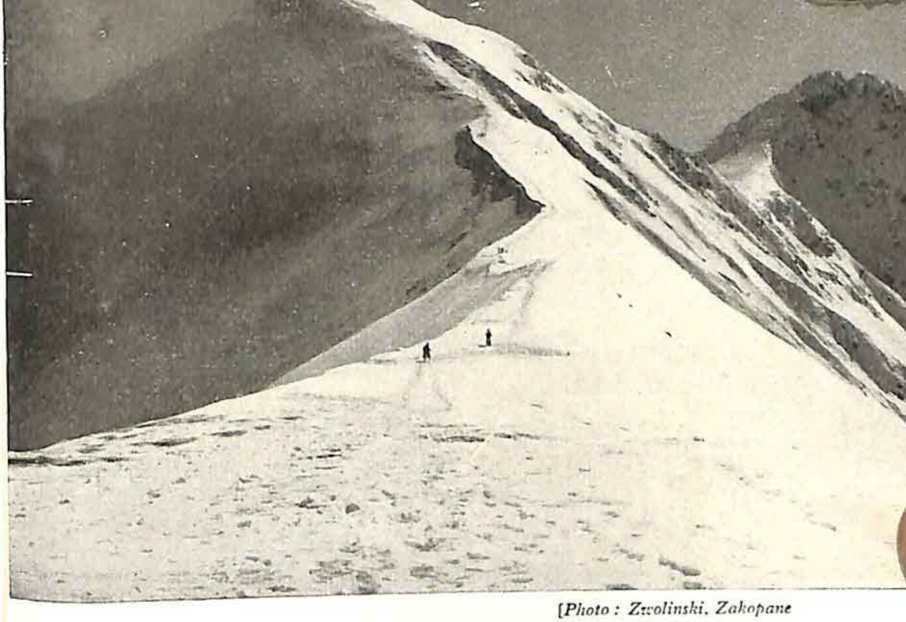
The important points to note in connection with rainfall are:

(*a*) The time of year when most rain falls.

(*b*) Whether the rainfall is good, moderate, poor, or very poor. In the tropics above 80 inches is good (if much higher it may be excessive), 40 to 80 moderate, 15 to 40 poor, and below 15 very poor. In temperate regions both evaporation and rainfall are less. Above 40 inches is good, 15 to 40 moderate, 5 to 15 poor, below 5 very poor. It is largely owing to differences in evaporation that a winter rainfall of 6 inches in the temperate areas of Australia is of more value than a summer rainfall of 12 inches in the Australian tropics.

Weather.—Pressure, temperature, winds, moisture, rainfall, etc. together make what we call the Weather. Sometimes one seems more important than the other and we can say it is wet weather to-day, or perhaps it is very cold weather, or cloudy weather. We can talk, too, about the weather for the week or the month. Sometimes for a whole week we may have very stormy weather. In tropical regions such as India the weather does not change very quickly. In the middle of the dry season there may be a wet period, but not very often. In other countries, including our own, every day may be quite different. One day may be wet and cold, and the next day cloudless, sunny and quite hot. In such countries everybody is very interested in the weather, and many of the newspapers publish every day weather maps showing the state of the weather.

Climate.—Climate is the average of the weather. We have summer and winter but precipitation occurs at all seasons of the year. Countries round the Mediterranean Sea have quite a different type of climate. In the case of this type of climate we can divide the year into a short, mild, moist winter, and a long, hot, dry summer. Every year there are these seasons. In some years the rain during the winter or rainy season is very abundant ; in other years not nearly so much rain falls. But that does not make any difference to the truth of the statement that each



[Photo: Zwolinski, Zakopane

FIG. 120. A good example of a climatic divide (Carpathian Mountains, High Tatra, between Poland and Slovakia). Bright sunshine on one side, cloud and storm on the other

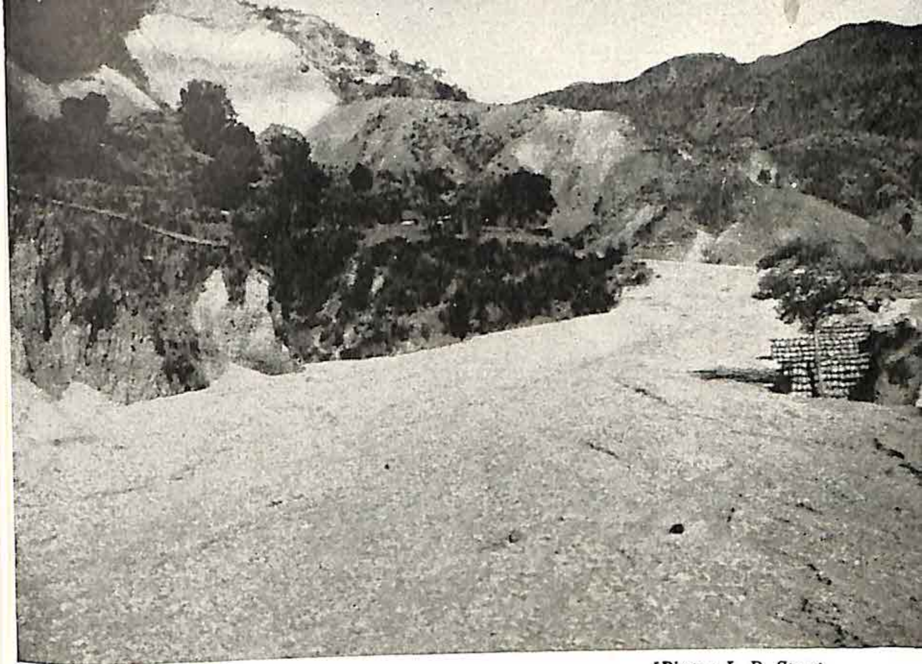
year has its wet winter and dry summer. Sometimes we may experience a warm day in the midst of the winter, and we can say that the weather for that day is exceptional. But one exceptional day does not alter climate, because the climate refers to the normal or usual condition of the weather. If we observe every year carefully for many years the amount of rain which falls during any particular month, or during the rainy season, we can get the *average rainfall*; in the same way, we can find the average temperature, pressure, humidity, wind direction, etc. All these averages—for a month, for a season, or for the year—considered together will record the *climate*. We can further illustrate the climate by noting the extreme high and low values observed within these several periods, for example the highest temperature ever recorded in July, or the lowest annual precipitation.

CHAPTER IX

GEOMORPHOLOGY

Geomorphology.—We have now considered the structure of the Earth's crust, the nature of the rocks of which it is composed, the processes of denudation and deposition which are continually operating on its surface and the climatic conditions which are largely responsible for those processes. We have now to study the *land-forms* which result, and the connection between the physical features which we can see and the underlying geological structure. This forms the subject matter of *geomorphology* (Greek : *ge* = the earth ; *morphe*, form ; *logos*, learning). Landscape and the land forms depend on *structure*—the structure and character of the rocks—on the *process* of denudation involved and the *stage* which that denudation has reached.

The Erosion Cycle.—After a great period of mountain building we can think of the surface of the earth as consisting of huge mountain chains of upfolded strata, with deeply hidden cores of granite, and perhaps with many volcanoes. Between the ranges will be deep valleys formed by downfolds of the rocks ; the sea may fill some of the deeper folds and only where the sedimentary rocks have been little disturbed should we expect plains. After a period of earth movement the topography is *highly accidented*, but immediately the forces of denudation get to work and start to wear the whole land down to sea-level and to pile the débris into

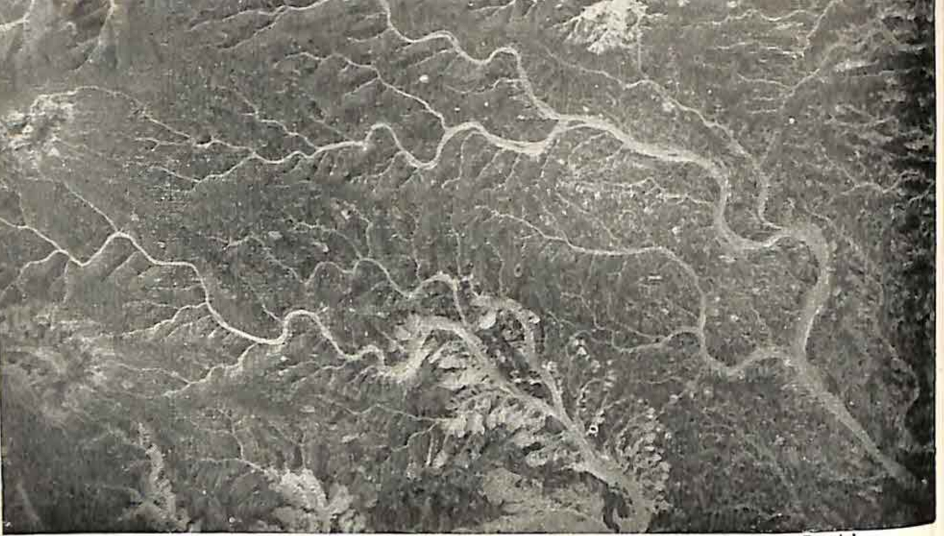


[*Photo : L. D. Stamp*

FIG. 121. Torrent action in the Himalayan Foothills, near Dehra Dun

The great scar on the hillside shows the source of the masses of partly rounded pebbles in the foreground.

the sea so that the sea itself is gradually filled in. At first frost action on the high mountains will cause great screes of angular rock to fill the valleys with breccia ; torrential rains on the high mountains will cause rushing streams able to move great boulders and huge stones which are swept down into the valleys towards the sea. The valleys themselves may be filled temporarily with fresh water and form turbid lakes. Then as the mountains are worn down the action of frost becomes less severe, the mountain torrents slower, the débris brought down by the rivers smaller. The steep-sided young



[Photo: Courtesy of the late Major Cochrane-Patrick

FIG. 122. The River Systems developed in the Deserts of Egypt

Seen from the air.

valleys become wider and more mature, the rivers deposit much of their load and build up alluvial plains. The ridges or interfluves between the river valleys are lowered. Gradually the whole land is worn down to gentle rolling country—almost a plain—and denudation practically ceases. The surrounding seas, instead of being disturbed with the pouring in of much sediment are clear and quiet. The land has been worn down to almost a plane surface, *i.e.* to a peneplain or peneplane (Greek: *pene* almost). Only a few isolated hills are left to break the rolling surface. These are called *monadnocks*. Thus *sub-aerial peneplanation* ends the cycle of erosion and it needs new earth-building movements before another cycle is commenced. Few parts of the world have reached the final stages—we find actually nearly all stages of the cycle of erosion in evidence. It only needs a slight movement of elevation to put new life into the rivers and to start them again on their work of deepening their valleys, so there are often signs of *rejuvenation* even in a mature landscape. Thus where a peneplane is uplifted rivers start dissecting the surface again and often the only indication of the old peneplane is that the summits of the hills reach almost the same level when seen from a distance. This is the case with the mountains of Wales.

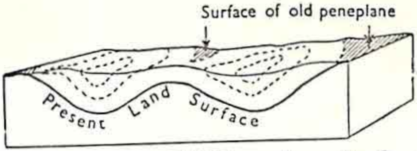
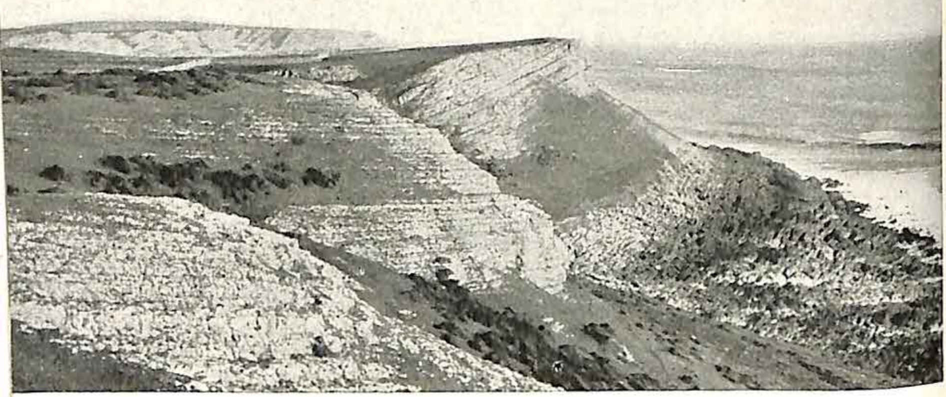


FIG. 123. An Old Peneplane Surface

Classification of Land Forms.—De Martonne distinguishes the chief types of topography as fluvial, glacial, coastal, aeolian, volcanic, and tectonic. But land forms differ according to climate, and the following classification is slightly different.

Land-Forms in Glaciated Country. — In a land covered with an ice-sheet certain peaks, usually very rugged because of frost action, appear as islands above the level of the ice; these are *nunataks*. If we could imagine the ice-sheet removed we should find the whole country, except the projecting nunataks, smoothed and undulating, the beds of harder rock standing out as low ridges, and the beds of softer rock or lines of weakness scooped out to form hollows. So in country which was once covered with a great ice-sheet, such as the Canadian Shield or Finland, we find the soil and loose rocks swept away, the hard rocks often scratched



[Photo : L. D. Stamp

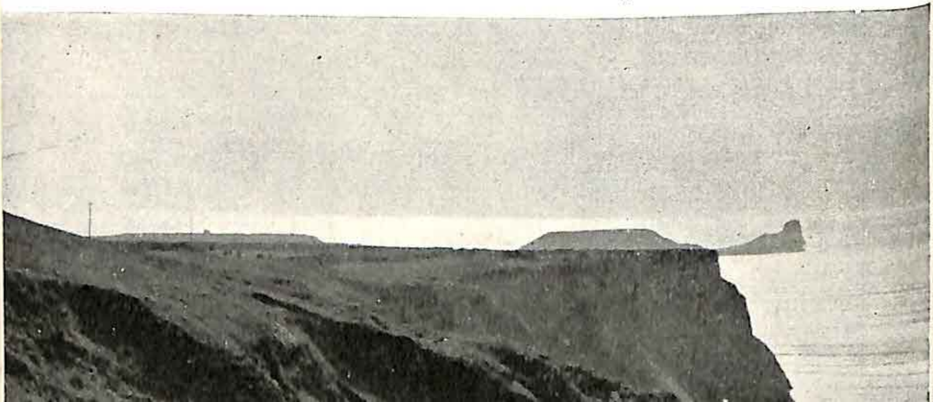
FIG. 124. The Peneplaned Surface of the Gower Peninsula, South Wales

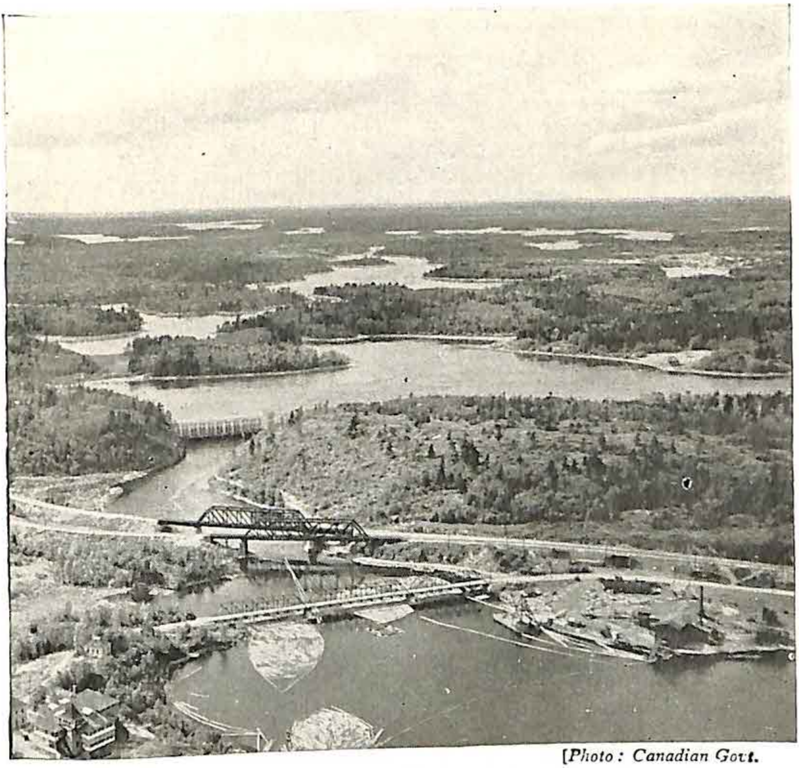
Notice that the surface of the peneplane bears little relation to the dip of the limestone.

FIG. 125. Peneplaned Surface in South Wales

Notice that the peneplane is continued on to the island.

[Photo : L. D. Stamp





[*Photo: Canadian Govt.*

FIG. 126. Aerial View of Glaciated Country—Part of the Canadian Shield

and polished and the hollows occupied by innumerable lakes. The lakes may be connected by sluggish streams, but waterlogged marshy country is common. On the margins of the old glaciated country conditions are quite different since they are the tracts where the glacial débris has been deposited. Again the country will be undulating; there will

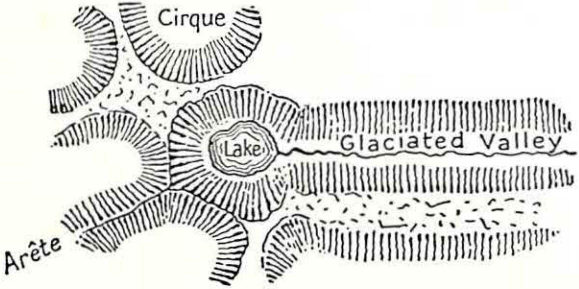


FIG. 127. Map of Mountain Range with Glacial Features

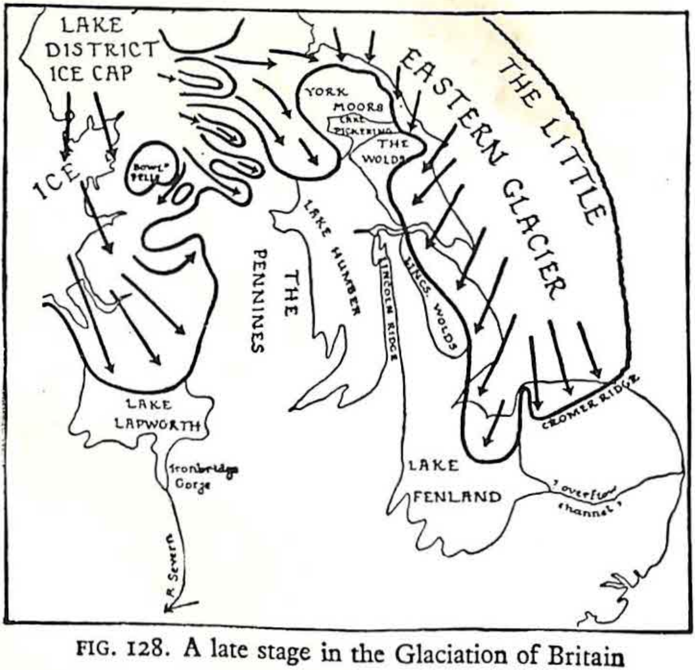
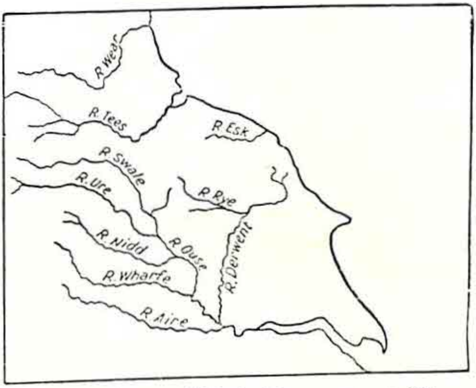
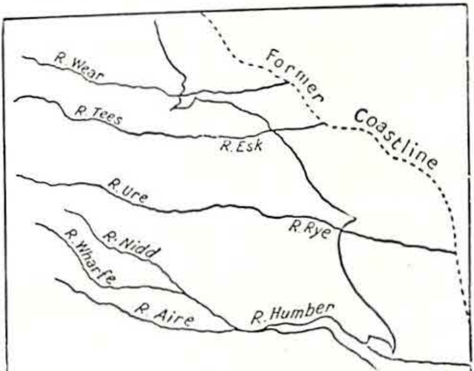


FIG. 128. A late stage in the Glaciation of Britain



A. Drainage of Yorkshire—present day



B. Drainage of Yorkshire—pre-glacial. The Little Eastern Glacier shown in Fig. 128 blocked the old course of the rivers

FIG. 129

be long ridges (moraines) dry sandy hills (drumlins) hollows filled with lakes or marshes (on glacial till) rivers which take unexpected courses (owing to glacial interference with the original drainage). Further away from the old centres of glaciation will be the great stretches of fertile loam or loess.

Somewhat different are the effects of glaciation on mountainous areas. There the head of a glaciated valley is marked by a steep-sided semi-circular *cirque* or *corrie* (*cwm*) with a circular lake (*cirque* lake). This marks the gathering ground of the snow. The valley below is U-shaped, probably straight, and marked by the absence of spurs. The old glacier may have scooped out part of the floor so that probably a lake will now exist, the water of which may be held up by a dam of moraine. Little streams may fall abruptly into the valley from lateral "hanging valleys," and there may be abrupt steps in the floor of the valley itself.

Land Forms in Temperate Lands.—Here the mountains are rugged owing largely to frost action, the mountain valleys young and narrow but V-shaped. On the lower ground the gentle topography is hilly or rolling, largely protected by vegetation, and its details depend mainly on the character of the rocks.

(*a*) *Horizontal sediments* give rise to flat-topped *plateaus* which are specialy marked if beds hard or resistant to weathering alternate with softer or less-resistant beds. The plateaus are often steep sided, especially if the rocks which compose them are well jointed vertically. Lava flows as hard beds and, because of the columnar jointing, often give rise to vertical cliffs on the edge of the plateau. This is well seen also in India (Fig. 149). If the horizontal beds are uniform in character gently undulating country may result. But even a bed of gravel may be sufficient to protect a mass of clay from erosion, with the result that flat-topped hills or small plateaus are left. In countries such as Spain with a low rainfall the sparsity of vegetation appears to accentuate the marked plateau or *mesa* topography.

(*b*) *Gently dipping strata* give rise to the well-known *scarpland* type of topography. The more resistant beds give rise to ridges (*cuestas*) with a gentle *dip slope* (coinciding approximately with the dip of the underlying rocks) on the one side and a steep face or *scarp-slope* on the other. The intervening valleys are often on clay (clay vales) and the fact that the rocks composing the ridges are usually pervious or porous limestones and sandstones results in the development of lines of springs as shown in the diagram.

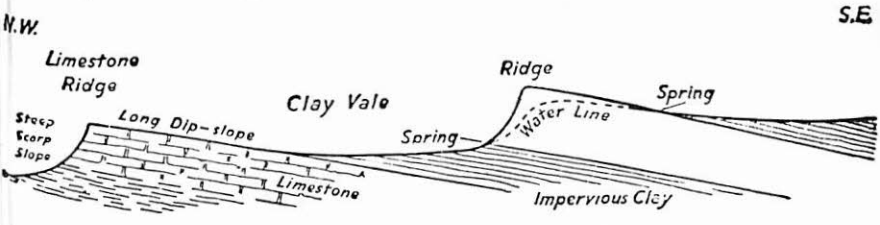
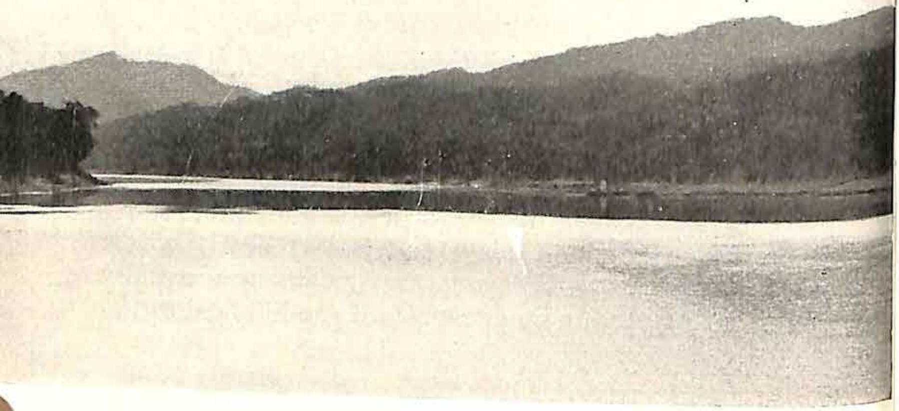


FIG. 130. Diagram of Scarplands

(*c*) *Steeply dipping or highly folded strata* often give rise to ridges (with a steep slope on both sides) corresponding with the outcrop of resistant rocks and valleys coinciding with the outcrop of the softer rocks. Not infrequently the most important element in the topography in such areas are level surfaces cutting across hard and soft rocks alike, which are old peneplanes (Figs. 124 and 125). Where the rocks are folded into anticlines and synclines there is often a marked tendency for anticlines to coincide with valleys, and synclines with hills (as shown in Fig. 132).



[*Photo : L. D. Stamp*

FIG. 131. Scarp and Dip Slopes seen amongst the Tertiary Sandstones along the Chindwin River, Burma.

(*d*) *Highly faulted country.* Here *horsts* and *graben* (troughs or rifts) may occur, bounded by *fault scarps.*

Land Forms in Dry Lands.—The land forms in deserts developed in sedimentary rocks are similar to those in damper temperate lands except that slopes are usually sharper and steeper as there is little rain to wash débris into the valleys and the rivers may cut deep, canyon-like valleys (*bad-land* type of scenery).

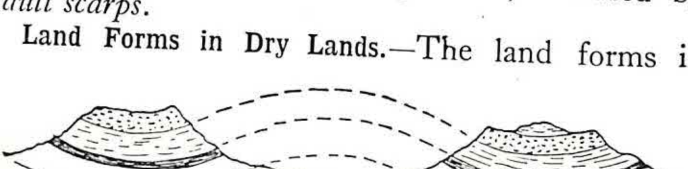
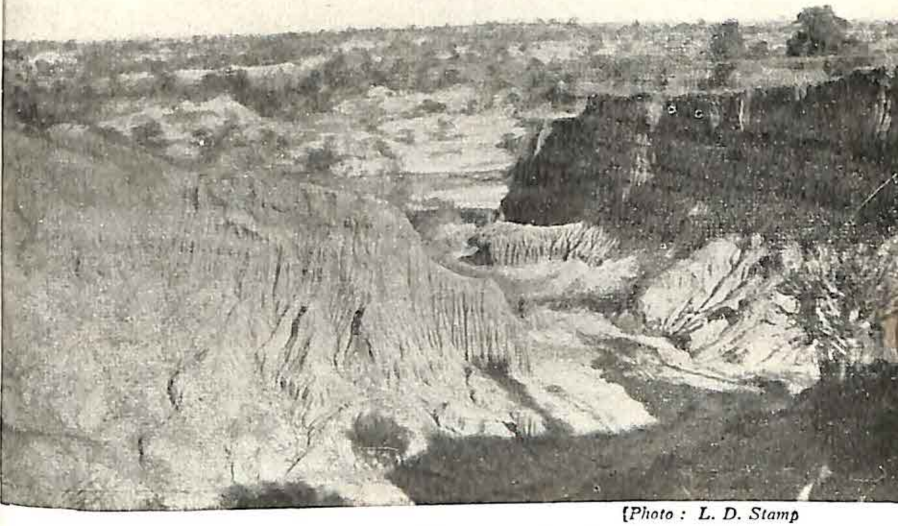


FIG. 132. Diagram of the Topography Associated with Anticlines and Synclines



[Photo : L. D. Stamp

FIG. 133. Bad-Land Type of Topography, Dry Belt of Burma

The action of the sun and wind are important in dry lands and so hard rocks may show rounded forms as shown in Fig. 10 (p. 15). Soil forms but slowly, and so lava flows, instead of giving rise to tracts of fertile land as they do very quickly in wet lands, remain as barren tracts (compare Fig. 61).

It is often found that mountains give place abruptly to a gently sloping plain strewn with boulders stretching away for great distances. This is known as the pediment, and the exact mode of its formation is difficult to decide. Such features are well seen in the drier parts of India.

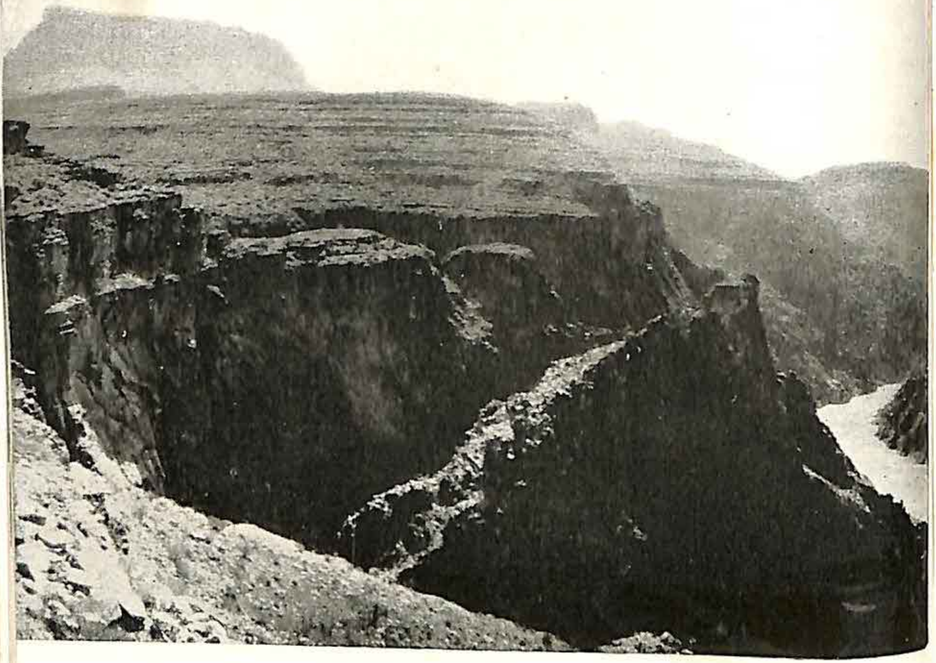
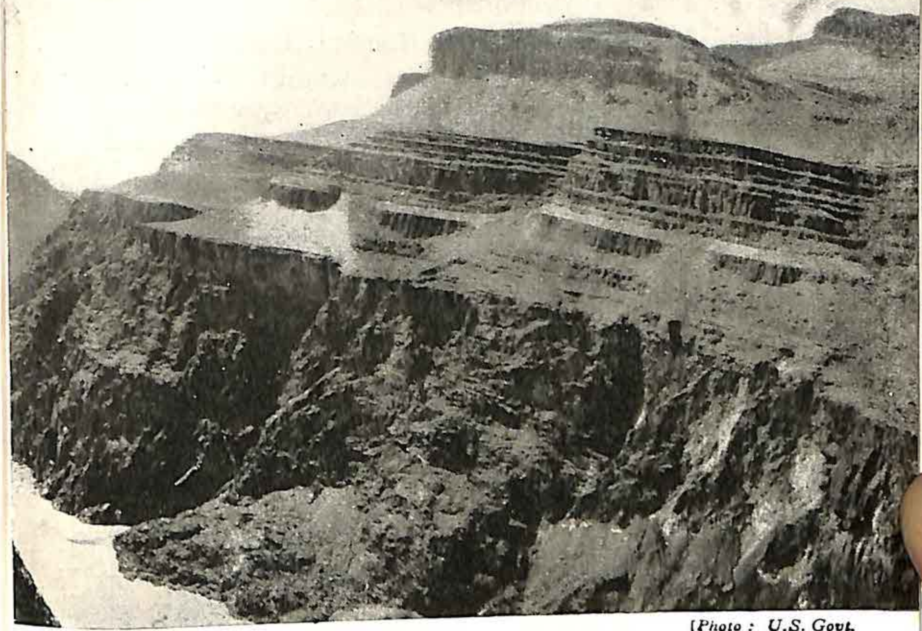


FIG. 134. The Grand Canyon,



[Photo : U.S. Govt.

Colorado River, Arizona

Land Forms in Hot Wet Lands.—Here the formation of a thick coating of laterite and the luxuriant growth of vegetation may obscure the connection between structure and topography. Sometimes, however, erosion by heavy tropical rains exposes the naked rocks of the ridges and permits insolation to play its part. Thus round *inselberge* (see p. 16 and Fig. 11) rising abruptly out of an undulating lowland or plateau are common features.

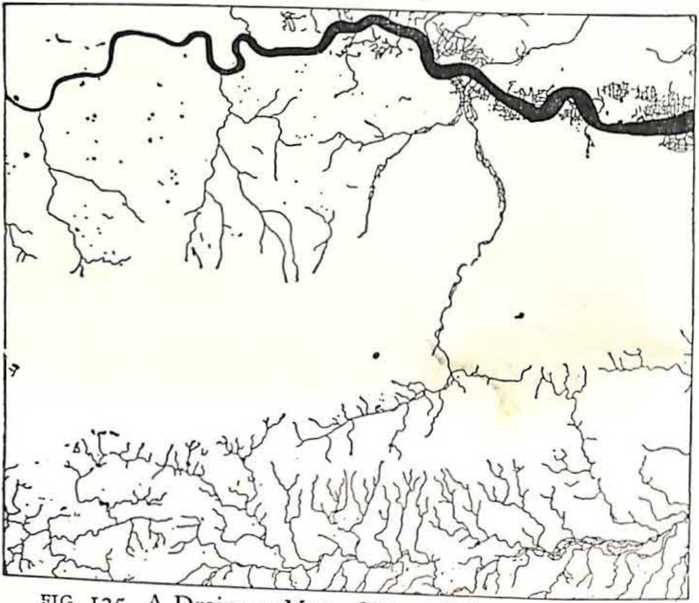
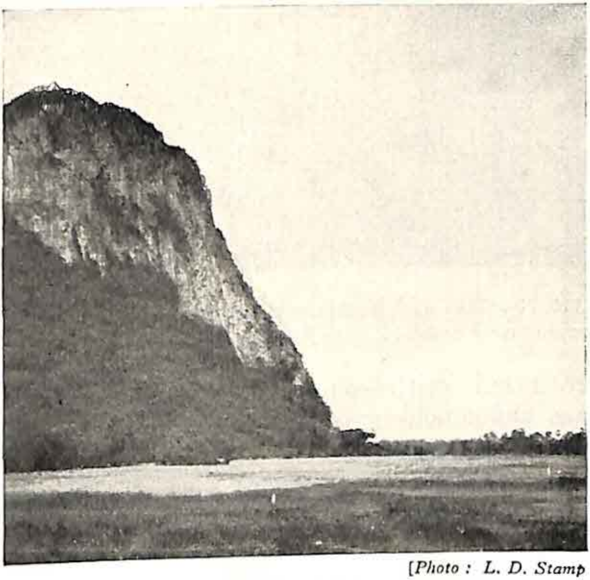


FIG. 135. A Drainage Map of Part of the London Basin showing the small number of Surface Streams on the Chalk.
The outcrop of the Chalk is marked by the broad east-west belt without streams

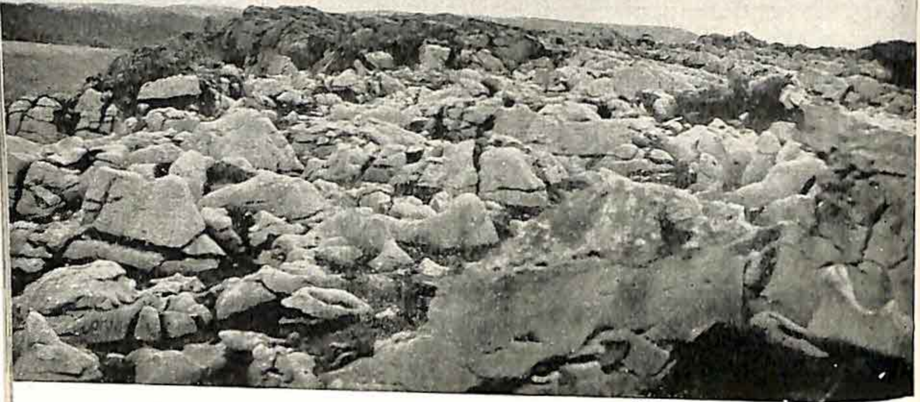
Land Forms in Limestone Country.—The land forms associated with limestone are peculiar because of the way in which water charged with carbon dioxide can dissolve the solid rock. Thus rainwater percolating underground eats out channels along the joints in the limestone, and much of the drainage may be underground. A stream or river may run along the surface for some distance and then disappear into a "*swallow hole*." If the swallow holes are later filled with gravel they form *pipes*, common



[*Photo : L. D. Stamp*

FIG. 136. Steep-Sided Hills of Limestone, Lower Siam. Vertical Jointing is partly responsible

in chalk country. In other cases stream beds are dry except in very wet weather, for the normal flow is underground. There are *bournes* of the chalk country in the south of England of this nature, and the chalk country is marked by an intricate system of *dry valleys* with no stream at the bottom. In the case of chalk and soft limestones the hills have

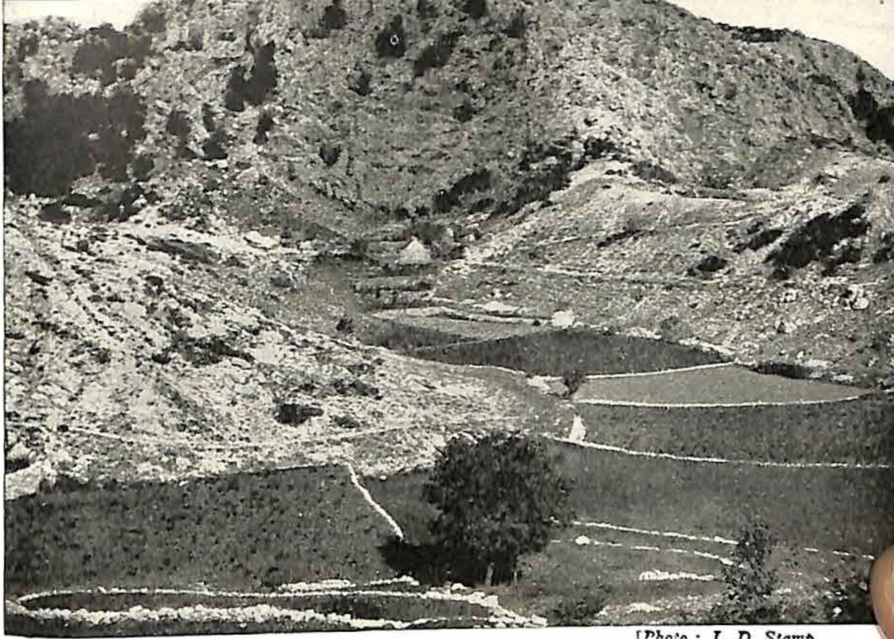


[Photo : L. D. Stamp

FIG. 137. Surface of Limestone dissolved to form Grikes
Carboniferous Limestone, near Buxton, Derbyshire, England.

gently rounded outlines; in the case of harder limestones the surfaces are often seamed with solution hollows or *grikes* (*clints*). There are often ill-drained marshy areas due to the irregular drainage, and caverns are common. The features associated with limestone are well displayed in the Karst country (Istrian Peninsula and Dalmatian Coast), and all the phenomena mentioned are often called *Karst* or Karstic phenomena. When the surface limestone is dissolved the insoluble residues may remain (*e.g*. clay with flints on the chalk in England, terra rossa in Mediterranean lands).

Land Forms Associated with Marine Denudation.—The sea is capable of cutting almost level surfaces (see p. 36), and if such a surface is elevated above sea level it forms a peneplain (marine peneplanation)



[Photo : L. D. Stamp

FIG. 138. A *Dolina* or Hollow with no Outlet, in Karst Country (Montenegro)

(Fig. 125). More often perhaps wave-cut platforms with remains of beach deposits, backed by old cliffs, are found elevated above sea-level (raised beaches). These are features associated with a raised or rising coastline. Along a sunken or sinking coastline the sea invades valleys forming *rias* between headlands. When the sea has invaded steep-sided glaciated valleys (often with a morainic ridge now submerged near the mouth) *fiords* result.

Where mountain chains run parallel to the coast lines a *Pacific* type of coast results; where the margins of the ocean are formed of faulted blocks or the coast lines instead of running parallel to fold lines are largely independent of structure, an *Atlantic* type of coast results.

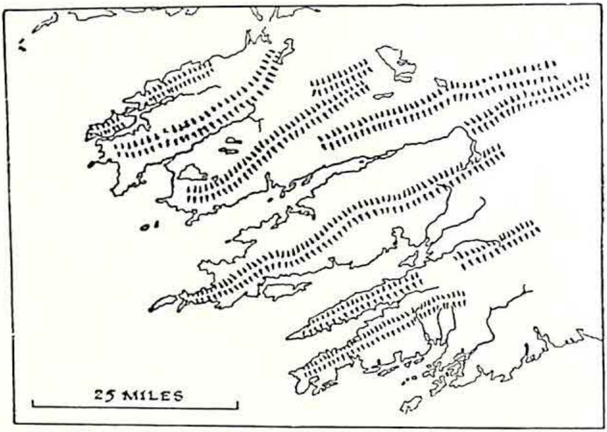


FIG. 139. A Ria Coast Line (An Atlantic Type of Coast)

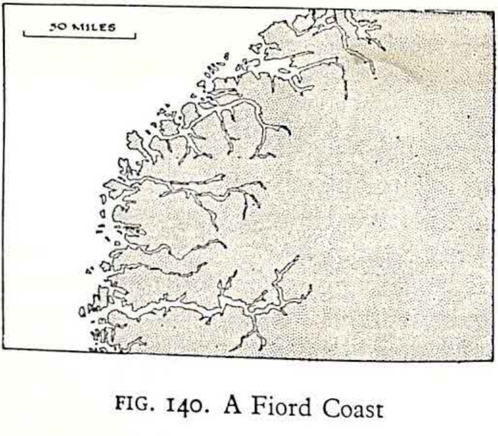


FIG. 140. A Fiord Coast

The Evolution of Rivers.—In the section on denudation we have already referred to the fact that a river's work may be generally described as denudation in its upper course, transportation in its middle course, and deposition in its lower course. As a landscape develops towards maturity the relative importance of these functions changes and a river undergoes a steady development or evolution. It is only possible here to study a simple case. Let us take what happens when the land is uplifted so that the sedimentary rocks form an anticline or a gentle slope. The rain which falls naturally drains down the slope and the stream which results is a direct consequence of the structure. It is therefore referred to as a *consequent* stream. If such a stream is flowing over a uniform system of rocks a

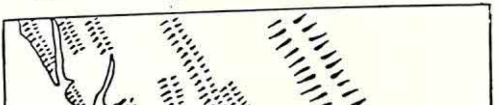


FIG. **141**. Map of the Pacific Type Coast of Western **Burma**

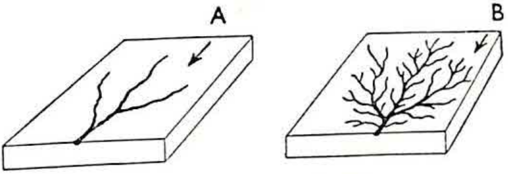
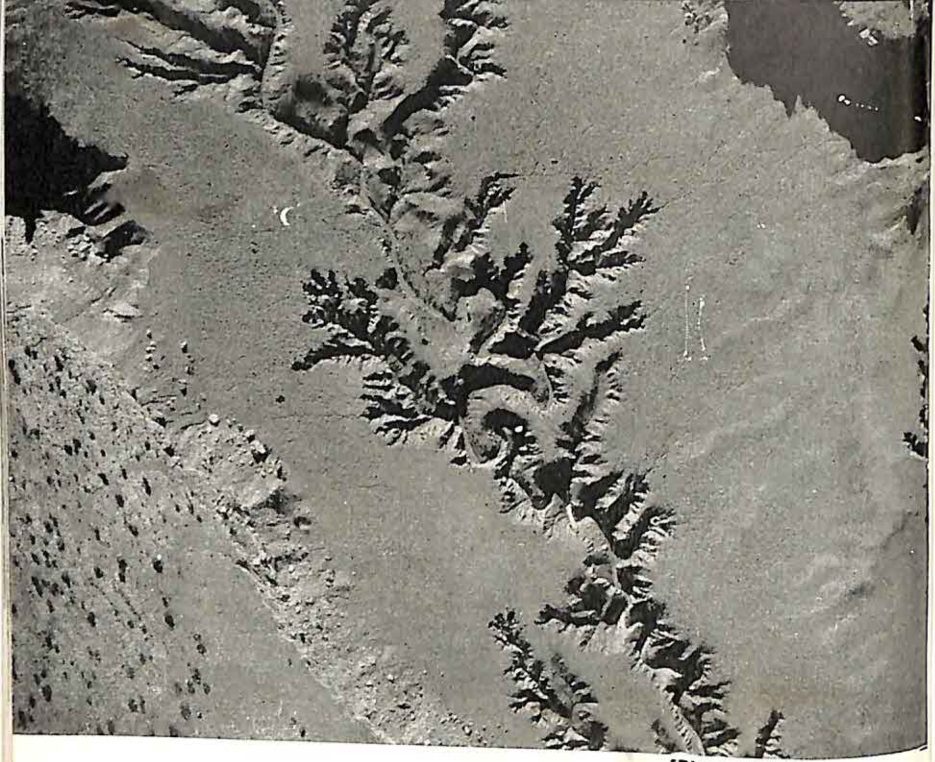


FIG. 142. Dendritic Drainage



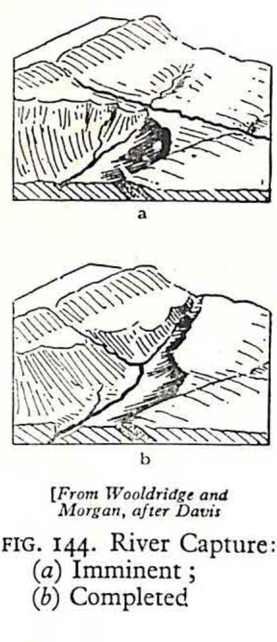
[Photo: U.S. Govt.

FIG. 143. Aerial View of Dendritic Drainage

A reservoir in semi-desert country in New Mexico (note the scattered bushes on the bottom left) had become filled up with mud and abandoned. The photo shows the new drainage developed on the almost level surface of mud.

dendritic form of drainage may result. If, on the other hand, the rocks consist of alternating resistant and less-resistant rocks the consequent stream cuts down into the whole series (in a *transverse* or dip valley—across the structure) but lateral streams develop along the softer beds, that is to say, they drain the clay vales and form tributaries which enter the main river at right angles. As these develop later or subsequently they are called *subsequent* streams.

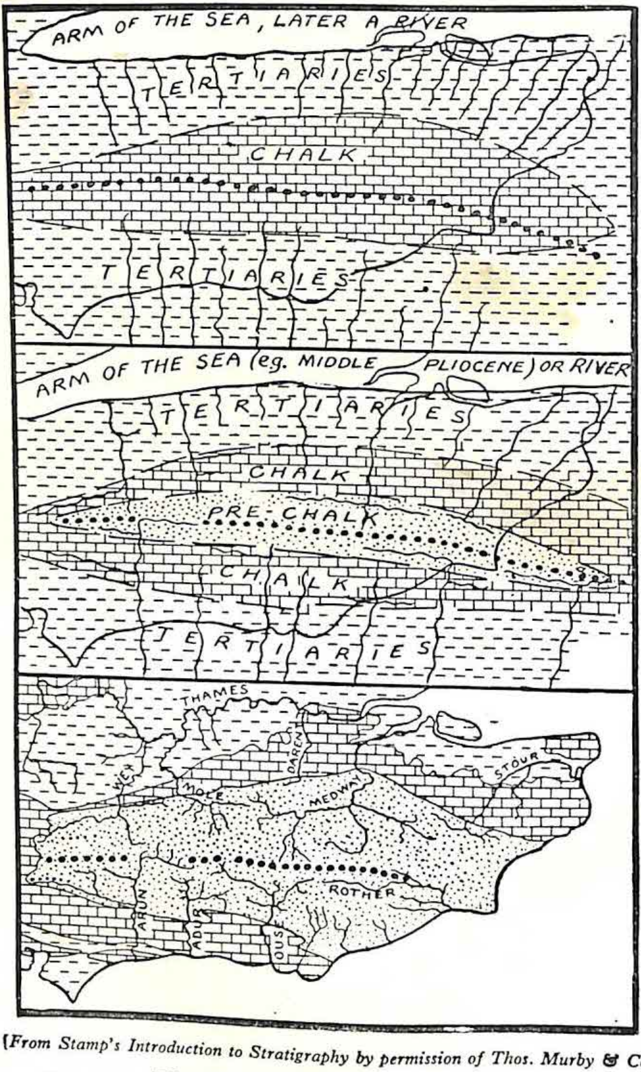
Each valley drained by a subsequent stream has naturally a gentle dip slope on one side and a steep scarp slope on the other. They run *parallel* to the structure in *longitudinal* (strike) valleys. There must be some streams draining from the scarp slope which actually flow in a direction opposite to the dip—that is, opposite to the consequent streams—and these are called *obsequent* streams. But the development of these streams is not regular. Some rivers become more powerful than others, and so cut down their valleys more rapidly. They begin to steal the rain water which ought to drain into another river and so become still more powerful while the river which is robbed becomes feeble. So one river may capture the headwaters of another. What was once only a tributary—a subsequent stream—becomes the main river. These changes may be well seen in the Weald of southern England, as shown in the diagrams.



[*From Wooldridge and Morgan, after Davis*

FIG. 144. River Capture:
(*a*) Imminent;
(*b*) Completed

At the same time as these changes are taking place the characters of the river valleys alter. The narrow mountain valley becomes gradually the broad mature valley of the plains. In a mature river the general slope from the source to the mouth (not necessarily following each curve of the river, but following a general course to which the term



(From Stamp's *Introduction to Stratigraphy* by permission of Thos. Murby & Co.

FIG. 145. The Evolution of the Wealden Drainage

"thalweg" (German—valley way) is applied), assumes a curve as shown in Fig. 146). A river which is old enough to have assumed this curve is said to have *graded* its bed. In the lower part of its course such a river has reached its *base level*, and cannot cut downwards any further—instead it

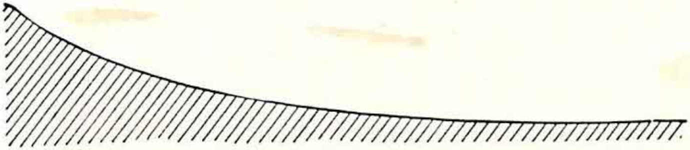


FIG. 146. Section of a Thalweg

begins to wander from side to side of its valley and to erode laterally. Thus the mature river winds its way lazily to the sea, following wide curves or *meanders*. It is often possible to trace by deposits of gravel and alluvium where the floor of the valley was at an earlier period, as these old valley floors form *terraces* on either side of the present

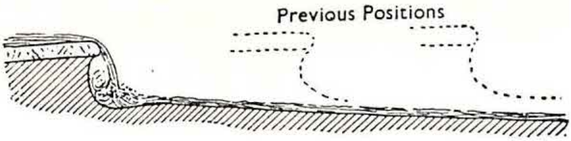


FIG. 147. Development of a Waterfall

stream and its valley. A river often cuts later into its own terraces. Then the river may cut a shorter course and leave an *abandoned meander* either with a lake (ox bow lake) or a marsh. In a young river an outcrop of hard rock may cause rapids or a waterfall, but gradually the river cuts down almost independently of hard bands. A

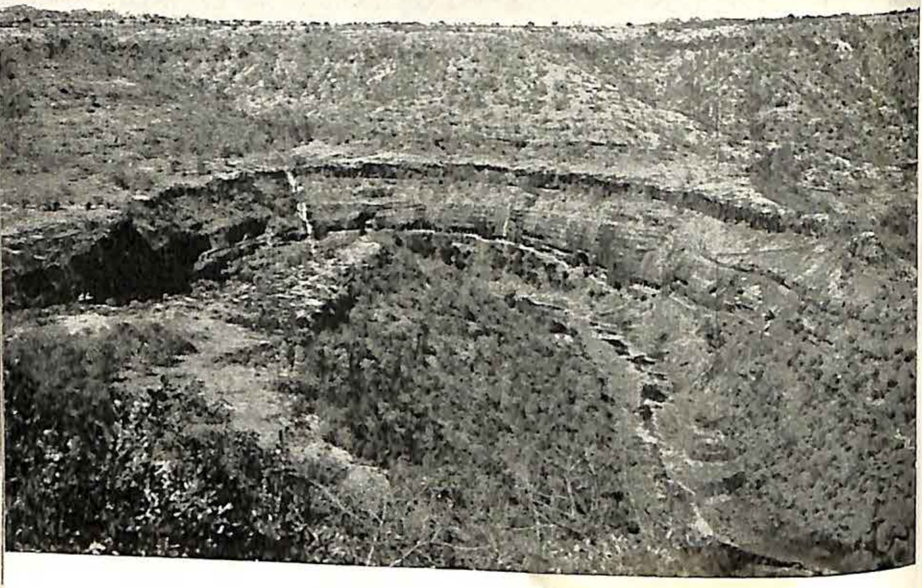


FIG. 148. Part of the Ajanta

This view illustrates the topography of flat-topped hills associated with
steep-sided almost vertical scarps which result, and the type of scrub-
inches). This picture shows a fine example of entrenched meanders.

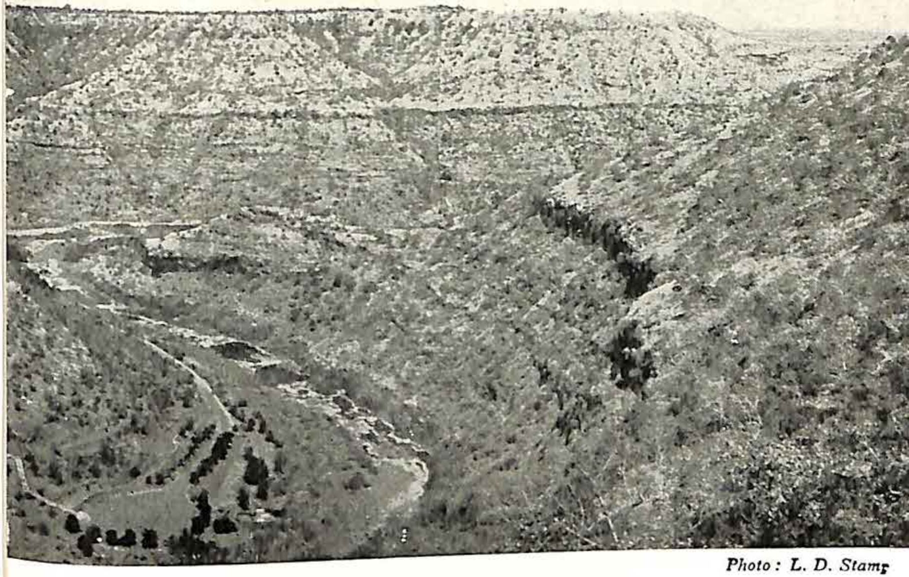
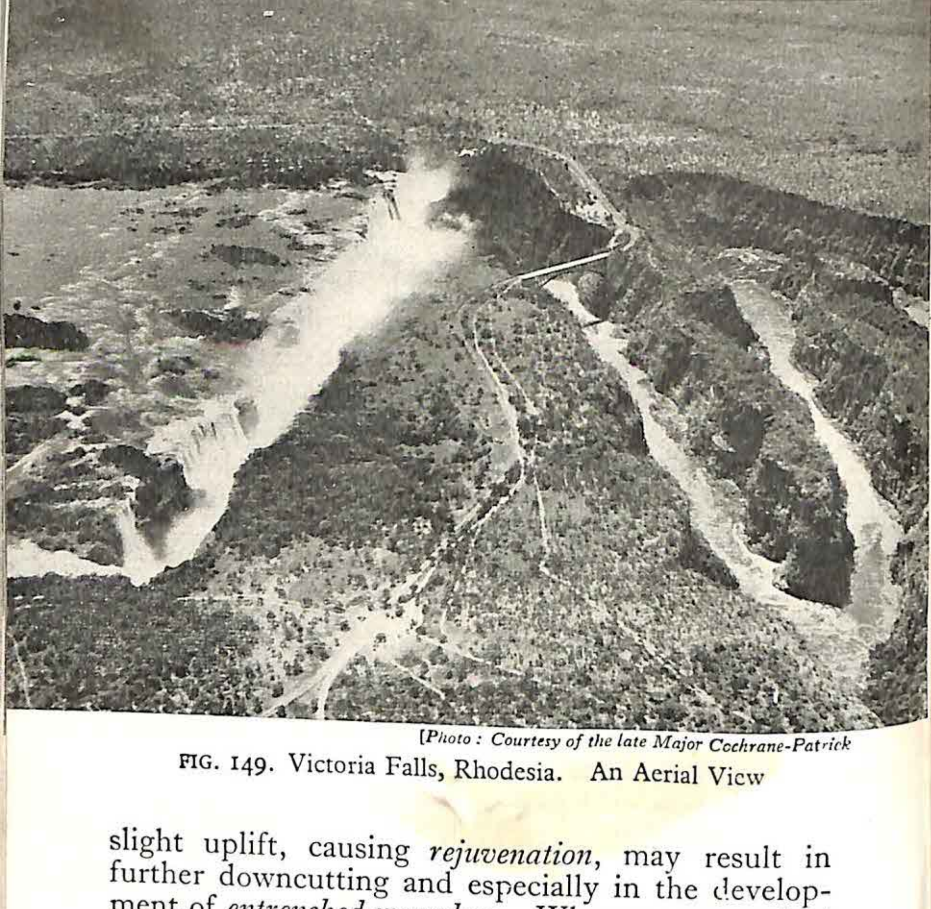


Photo : L. D. Stamp

Range, Hyderabad State, India

the Deccan Lavas of India, which are almost horizontal. It shows the woodland or dry savana, found in the drier parts of India (rainfall 30



[*Photo : Courtesy of the late Major Cochrane-Patrick*

FIG. 149. Victoria Falls, Rhodesia. An Aerial View

slight uplift, causing *rejuvenation*, may result in further downcutting and especially in the development of *entrenched meanders*. Where an entrenched meander is later abandoned a *meander-core* is left. Rejuvenation is also marked by the development of sudden breaks (knick points) in the slope of the river with rapids which may be quite independent of the position of hard bands. On the other hand slight movements of depression may result in the silting up of the river bed, the development of marshy, ill-drained tracts, and perhaps of shallow lagoons or lakes cut off from the sea by shingle bars. The coast of Texas abounds with examples.

Some consequent river systems have been initiated on surfaces of rock which have since been completely worn away. The rivers have cut down to underlying older rocks and seem now to have no relation to the structure. Such drainage is said to be *superimposed.* It will be remembered that the Brahmaputra river cuts right across the Himalayas and it is believed by some that the river was initiated before the mountains arose and that the river in its work of downcutting, kept pace with the rising mountains. Such drainage is termed *antecedent.*

CHAPTER X

SOIL AND UNDERGROUND WATER

Definition of Soil.—It used to be said that the soil was simply the upper layer of the earth's crust in which plants grow. But the study of soils or *pedology* has now become an important science of its own. The soil may be defined as the outer layer of the land surface which is usually of loose or unconsolidated matter; it varies in thickness from a mere film to several feet; it usually differs in a number of ways from the underlying rock—in colour, structure, texture, physical and chemical composition, and in biological characters.

In most forms of soil it is possible to distinguish three horizons (A, B, and C) which together constitute the *soil profile*.

The Formation of Soil.—The soil is the result of three processes of weathering:

(*a*) Physical weathering, which we have already considered, whereby the original rock material is broken down to form the parent material of soils.

(*b*) Chemical weathering, whereby chemical changes take place in the original constituents and result in the differentiation of the horizons.

(*c*) Biological weathering, whereby the action of plants and animals—especially the roots of plants and such animals as earthworms—causes great changes to take place both in chemical and physical characters.

The underlying rock provides the parent material and may be described as a " passive soil former " whereas rainfall, temperature, humidity, evaporation, plants and animals are continuously at work and may be described as active soil formers. Thus soils often depend more on the climate, including soil climate, than on the underlying rocks.

The Soil Profile.—The upper layer, or A horizon, comprises a surface or A_0 layer which consists of, or includes, the undecomposed or incompletely decomposed remains of the growing flora. Below it is the A_1 horizon where percolating waters dissolve organic and mineral salts and wash them downwards. This horizon thus suffers from *leaching*, the washing out of material. The material washed out of the A horizon is caught or deposited in the B horizon which is thus a zone of secondary enrichment. Below the B horizon is the C horizon which usually resembles somewhat closely the underlying geological rock and which used to be called the subsoil.

The Great Soil Belts of the World.—Because climate is the greatest factor in the formation of soil, the great soil belts of the world correspond closely with the great climatic regions.

(*a*) *Red and Yellow Soils of the Tropics*.—These are formed under conditions of high rainfall and high evaporation and often rest on a considerable thickness of the rock laterite (Latin : *later*, a brick). Laterite is formed by the action of percolating water dissolving and then redepositing iron salts to form a rock resembling a coarse brick. Tropical soils are often rather poor because the rain easily washes out of them the valuable plant foods.

(*b*) *Grey Desert Soils*.—These include solonchak or saline soils and are formed under conditions of rainfall less than evaporation.

(*c*) *Brown and Chestnut Soils of Dry Lands*.—These are formed under conditions where the moisture is insufficient to form black earth and where there is less humus.

(*d*) *Black Earths* or *Chernozem of the Rich Steppe-lands and Prairies*.—These are formed under conditions when rainfall and evaporation are nearly equal and when the winters are so cold that the decomposition of organic matter is brought to a standstill.

(*e*) *Brown Forest Soils of Deciduous Forests*.—These are varied and difficult to define. Most of the soils of Britain are brown soils but they seem to owe their characters largely to cultivation and the plough. Canada has similar soils.

(*f*) *Grey Podsols of Coniferous Forests*.—These are formed under conditions of good drainage, where rainfall is greater than evaporation. The surface layers are "leached" and hence become ash-coloured, the B horizon is enriched by deposition from above.

(*g*) *Glei Soils of the Tundras*.—These are formed when the subsoil is permanently frozen, so that the surface is frozen one part of the year and marshy the other.

There are of course many local types, particularly fen and peat soils. In Britain the soils vary greatly with the underlying rock groups rather than with local climate and are said to be *aclimatic*. In all parts of the world there are many *immature* soils where the profile has not yet had time to develop, as on mountains. On steep slopes the material washes slowly downhill (hill-wash or solifluction) and so there is a natural mixing of material.

Texture and Mechanical Analysis.—The mineral particles which form the bulk of the soil vary greatly in size and are grouped as follows :

Diameter	above 2 mm, ..	.. =stones or gravel
,,	0·2 mm. to 2 mm, ..	.. =coarse sand
,,	0·02 mm. to 0·2 mm,	.. =fine sand
,,	0·002 mm. to 0·02 mm,	.. =silt
,,	below 0·002 mm. . ..	.. =clay

Sandy Soils contains more than 60 per cent. of sand and less than 10 per cent. of clay. They are easily worked, but water drains away quickly, taking manure and plant food with it so that they are *hungry* soils.

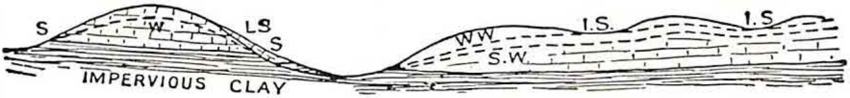


FIG. 150. Springs

W=Water Table ; WW=Winter Water Table
S. W=Summer Water Table ; S=Springs
I. S.=Intermittent Springs ; LS=Landslips.

Loamy Soils contain less sand and more silt and clay. They are easily worked and form good agricultural soils.

Clayey Soils contain a high proportion of clay. They are sticky when wet and hard when dry, and so difficult to plough, but support good grassland.

Calcareous Soils are those rich in lime.

Fenland Soils are dark and rich in humus and resemble chernozems, but peaty and moorland soils suffer from being badly drained.

Underground Water.—Of the rain which falls a certain proportion runs off the surface as streams and rivers, a certain proportion evaporates, and a certain proportion sinks into the ground. The amount that sinks in depends largely whether the rocks are *pervious* and allow water to pass through, or *impervious*, and prevent the passage of water. Rocks with small pore spaces soon become waterlogged; rocks with larger pore spaces can absorb and hold water. In the case of pervious rocks underlain by impervious ones the water accumulates and a *permanent water table* is found below the surface. The water in wells sunk into the ground rises to this level. After heavy rain the surface of the water table rises temporarily under conditions shown in Fig. 150. Water from the underground water table reaches the surface as springs under conditions shown in Fig. 150. Where the rocks are folded in the form of a syncline and a pervious, porous layer such as sand occurs between two impervious layers (as shown in Fig. 151), the water is imprisoned and if the upper impervious layer is pierced the water gushes forth sometimes with great force (artesian well).

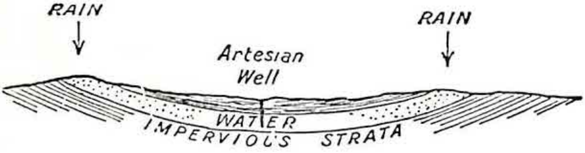


FIG. 151. Artesian Basin

CHAPTER XI

VEGETATION AND ANIMAL LIFE

Climatic and Vegetation Regions.—In the preceding chapters we have seen that the processes of weathering and the intensity of action of the geological agents vary greatly from one part of the world to another. The differences are due in part to the varying materials of the earth's crust, but in even larger measure to the varying climatic conditions. This became especially evident in the last chapter, where the major soil groups correspond with major climatic differences. We have now, therefore, to consider the chief types of climate found in the world and the influence which they have on vegetation and on animal life, including the life of man.

The Principal Climates and Climatic Regions of the World.—It is usual to distinguish twelve great climatic types. So clear is the connection between vegetation and climate that it is often simpler to name the climate after its characteristic vegetation.

(1) *The Equatorial Climate, or Climate of the Hot, Wet Evergreen Forests.*—This type is found as a belt stretching about 5° on each side of the Equator. The temperature is high all the year round, but does not vary very much ; an average for the whole year is about 80°. Rain falls nearly all the year, so that the air is always hot and moist and the climate as a whole unhealthy. The rains are mainly convectional. Owing to the great heat there is much evaporation. The water vapour rises to the upper part of the

atmosphere and is cooled and so falls as rain. Very often evaporation takes place during the morning and the rain falls in the afternoon, accompanied by thunder. Though rain falls throughout the year, there are typically two seasons rainier than the rest of the year. The Amazon and Congo basins are typical areas having this climate. Islands near the Equator—the East Indies—have a similar climate but with pleasant land and sea breezes, and so has the Malay Peninsula and New Guinea. Parts of Ceylon and the Guinea coast in Africa have a climate which is very nearly of this type.

The moisture and heat cause the growth of luxuriant trees, often of great size. All plants need light and air, and amid the dense, rank growth of the equatorial forest there is a constant struggle upwards to reach the light. The big trees grow tall and straight, with a crown of leaves at the top. Other plants reach the light by climbing up the trees—these are the lianes or woody climbers—and often grow to such a size as to kill the tree by which they climbed up. Other plants grow high up on the branches of the trees and reach the light that way. Thus the branches may be thickly clothed with ferns. In the tallest and densest equatorial forests the mass of leaves is so thick that no sunlight ever reaches the ground, and it is dark and gloomy. This is the case with many of the forests of the Amazon and Congo Basins. Other forests are not quite so thick, and a little sunlight may reach the ground. The forests of much of the East Indies are like that, and there we find a rich growth of smaller plants (undergrowth) on the ground. The trees of the equatorial forests are of very many different kinds, but most of them have very hard

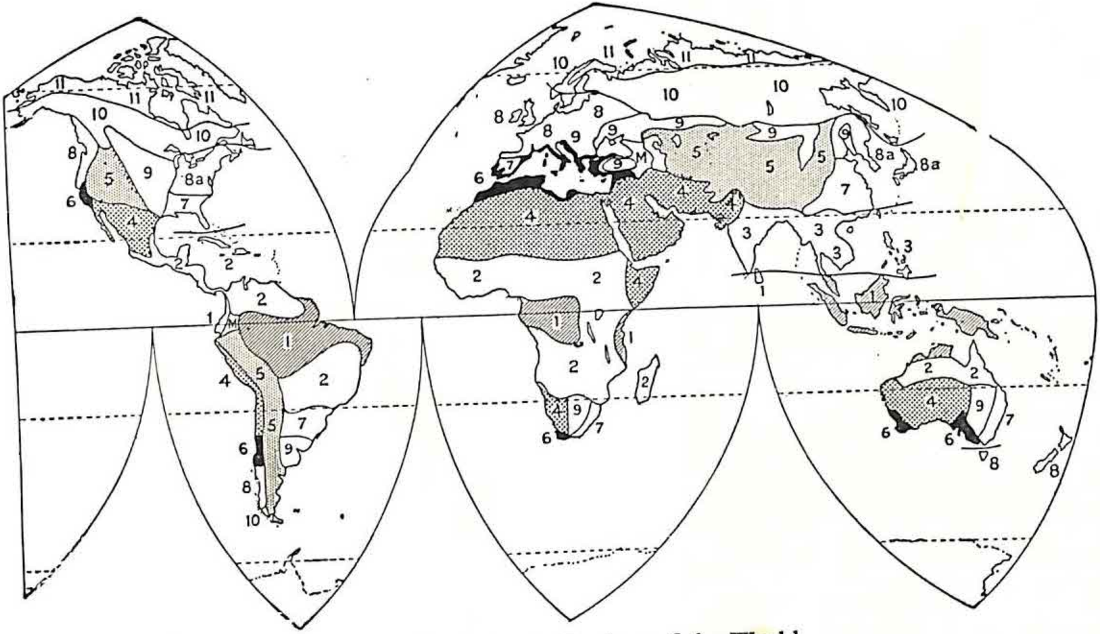


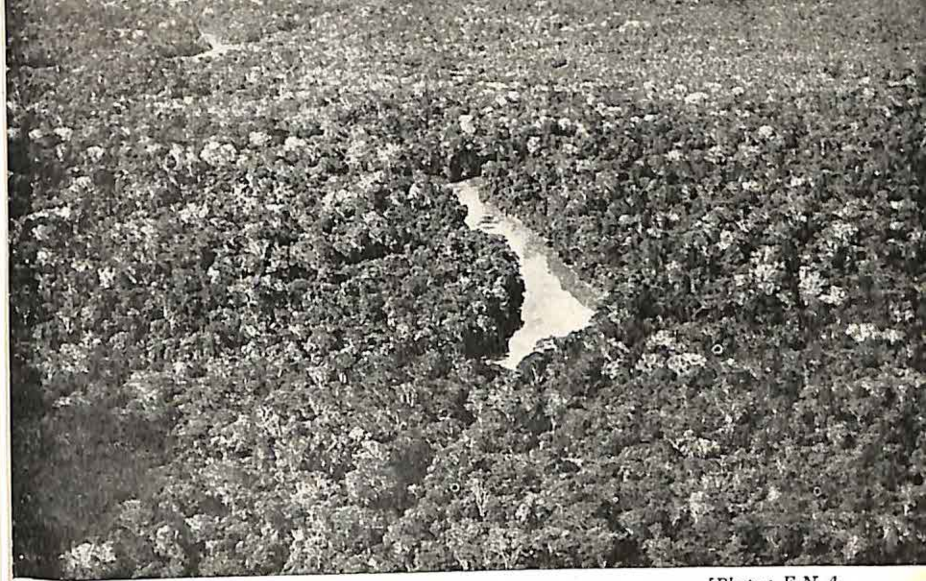
FIG. 152. The Climatic Regions of the World

wood. Much of the wood is very fine—like mahogany and greenheart; but it is very difficult and costly to cut down these great hard-wooded trees. Even the more easily reached evergreen forests are exploited to only a limited extent.

The equatorial forests are the home of the rubber trees, and rubber collecting is still an important industry in the Amazon forests of South America. But the most and best rubber is now obtained from plantations which man has made—on the fringes of the equatorial belt in Ceylon, Malaya, East Indies, and Lower Burma. Another useful tree is the cinchona, whose bark yields the medicine quinine. The cocoa or cacao tree belongs to these regions too, and also the manioc plant. Near the sea, on sandy shores, we find the coconut palm everywhere. Its big seeds, the coconuts, float and are carried by ocean currents, so that the palm is found on nearly all tropical islands. In Africa the Guinea oil palm takes the place of the coconut palm.

Animals, like trees, must have light and air, and so we find most of the inhabitants of the equatorial forests are adapted for climbing. The monkeys are typical. In the denser forests nearly all the animal-life is to be found in the treetops. There we find all sorts of animals specially adapted for climbing—tree-frogs and tree-lizards as well as birds, and a wealth of insect-life.

How is man to live in such forests? The hot, moist air is not good for his growth and development; it is never cold, so that little clothing is required. Many of the trees of the forest yield fruits fit for food. But it is very difficult to cut down the forest and carry on agriculture, for the forest grows up again very rapidly. So we find the



[Photo: E.N.A.

FIG. 153.—Flying over the Equatorial Forests of the Amazon Basin—an unbroken sea of trees.

equatorial forests are inhabited by very backward, uncivilized tribes; many of them, like the Pygmies of the Congo, are of very small size. They wear very little clothing and often have no huts at all, or build small shelters in the trees. Some of them, like the natives of the Amazon Basin, are hunters and wanderers. They live mainly on the jungle fruits. The climate makes difficult, though far from impossible, any improvement in agriculture or the arts. Where, however, the climate has been made the servant of man (as by the white man in Malaya or by the energetic native races of the East Indies) the equatorial lands are very productive.

(2) *The Tropical Climate, or Climate of the Savana or Tropical Grassland*.—This climate is found on either side of the equatorial belt, and is well developed in Africa. As usual, "rain follows the sun," and so the heaviest rainfall occurs soon after

the sun has been shining vertically, whilst the dry season occurs in the colder part of the year. This type of climate is found in the Sudan (Africa), and so is often called the Sudan type. The characteristic vegetation of the Tropical climate is a rich growth of tall grass with scattered trees (savana). A large area of Africa has a Tropical climate. Nearly all this country is covered with savana. In South Africa and Rhodesia it is called "bush veld." The grass springs up quickly during the rains, but later in the year is scorched by the sun, and the country is dry and brown during the hot season. Trees become more numerous as the rainfall increases. Many of the tropical grasslands have strong winds, and very much wind is bad for the growth of trees. We find many of the trees of the savana are umbrella-shaped, so that they expose only a narrow edge to the wind.

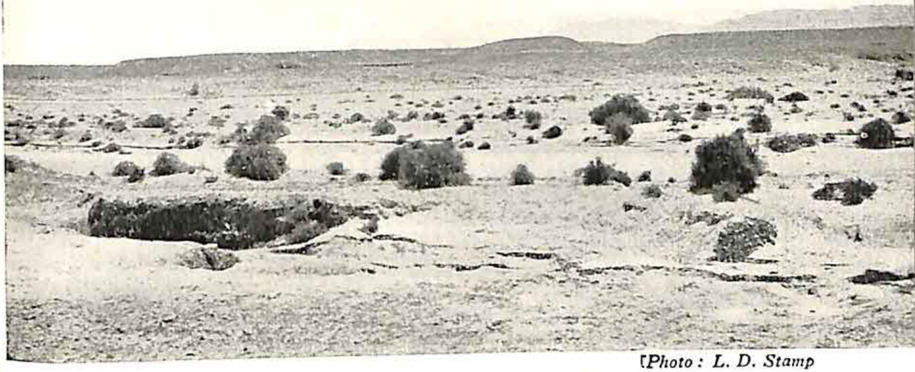
The animals of the equatorial forest are specially adapted for climbing—the monkeys, for example, escape from their enemies by their speed and cleverness in swinging from one tree to another. In the savana climbing animals would have few trees to climb, and so the animals are specially adapted to escape from their enemies by swiftness of flight. There are really two main groups of animals—the swift-footed grass-eating animals like the antelopes and giraffes, and the savage flesh-eating animals like the lion and tiger which live on them. Very often the grass-eating animals will be disturbed in the midst of a meal and have to run away. Many of them therefore swallow their food very quickly, and then when they are at rest are able to chew it over again—chew the cud. Just as the savanas (*e.g.* in Africa) have supported vast herds of wild grass-eating animals, so man is able to raise great herds of cattle on the tropical grasslands. So the inhabitants of the grasslands are at first hunters hunting the wild animals, later they become pastoral peoples interested in the keeping of herds of cattle. Read what is said of life on the temperate grasslands. It is very similar. There are great stretches of these tropical grasslands in the north of Australia.

(3) *The Monsoon Climate.*—The Monsoon climate is very similar to the Tropical climate, but the rainfall is caused in a different way. This climate is found typically in India and along the north-western coast of Australia. There is the cool season, with little rain, lasting in the northern hemisphere from about October to February; then the temperature begins to get higher and the hot season lasts from March to June. The rains break in June and last till September. Nearly all rain falls in the latter period. If these are the seasons in a monsoon area of the northern hemisphere, how would they be different in the southern hemisphere? Another name for the Monsoon climate is the Summer Rains climate, for the rain falls in the summer of the year. The summer would otherwise be very hot indeed, but the rains make it cooler. The Monsoon climate occurs around the Indian Ocean, especially in India, Burma, north-western Australia, and Abyssinia in Africa. There are small regions in north-western South America which have a monsoon rainfall. The natural vegetation of the monsoon lands is typically seen in India. The ground is covered with forests which lose their leaves during the hot season. Trees require a great deal of water, which they drink in through their roots and lose by evaporation through their leaves. In the dry, hot weather it is necessary that the trees do not lose too

much water. So in the monsoon forests the trees guard against this loss by shedding their leaves. When the rainfall is more than 40 inches the monsoon forests consist of fine large trees, of which teak and sal are familiar examples. But as the rainfall gets less and less the trees become smaller, and many of them are armed with thorns. The forest, as we say, passes into thorn forest and scrubland (of the type shown in Fig. 149), and finally into desert with only a few scattered shrubs. Monsoon forest is not as thick as equatorial forest and can more easily be cleared for agriculture. Many plants of great value to man flourish in the Monsoon climate. There are timber trees, bamboos, various palms, fruit trees like the mango and bread fruit, as well as plantains and bananas. More important still are the cereals: rice in the wet lands and millet and sesamum in drier parts. On certain soils cotton flourishes; tea and coffee grow well on hill slopes. Maize can also be grown and wheat as a winter crop.

The Monsoon climate is, then, very favourable to the growth of food crops. So we find most of the monsoon lands are very thickly populated. In some parts it is very easy to obtain sufficient food and the people get lazy, but if they do not let themselves get lazy there is great opportunity of progress; and so a high state of civilization exists in many monsoon lands.

(4–5) *The Climates of the Great Deserts.*—Passing from the region of the Tropical or Monsoon climates towards the Poles we find regions which are very hot and dry—so dry that scarcely any plants can grow. These regions lie mainly in the high-pressure belts just outside the tropics. The trade winds blow away from them towards the Equator, the westerly winds blow away from them towards the Poles, and



[Photo : L. D. Stamp

FIG. 154. The Egyptian Desert, showing in the foreground a sparse vegetation of shrubby plants made possible by the existence of water underground. Notice the flat topped plateaus in the background

there are no winds which bring rain into the regions. Some of the regions are dry, too, because, like the centre of Asia, they are very, very far from the sea. There is very little rain and no clouds, so that the sun's rays strike down fiercely on to the ground and make the days very hot indeed. The highest temperatures in the world are found in these regions. But at night the ground loses its heat very quickly, and so the nights are cool. These are the lands where weathering by the sun's action is most marked. We may divide these deserts into two groups:

(*a*) The Hot Deserts, occupying lowlands along the Tropics of Cancer and Capricorn. Examples are the Sahara Desert, the Desert of Arabia, and the Great Indian Desert. In the southern hemisphere there are deserts in Australia, South Africa (Kalahari), and South America (Atacama).

(*b*) The Temperate Deserts, usually found on plateaus outside the tropics. They are much colder in the cold season, and may be covered with snow. Examples are the deserts of Iran or Persia, the deserts of Gobi in Asia and Colorado in North America. In talking about the monsoon lands we said that as the rainfall gets less the monsoon forest becomes poorer and poorer, passes first into scrub-land and then into desert. In the same way grassland becomes poorer and poorer, and passes eventually into desert. Thus desert is sometimes very, very poor grassland ; at times very, very poor scrub or woodland. There are few deserts where absolutely *nothing* grows. Desert plants have different means of storing water. Some of them have very very long roots which go down to great depths and there reach water ; many have fleshy stems and leaves in which they can store up water ; many prevent the loss of moisture by covering their stems and leaves with a thin coating of wax ; the Australian eucalypts do so by turning their leaves edgeways to the rays of the sun ; still others are armed with sharp spines and thorns which protect them from being eaten by animals.

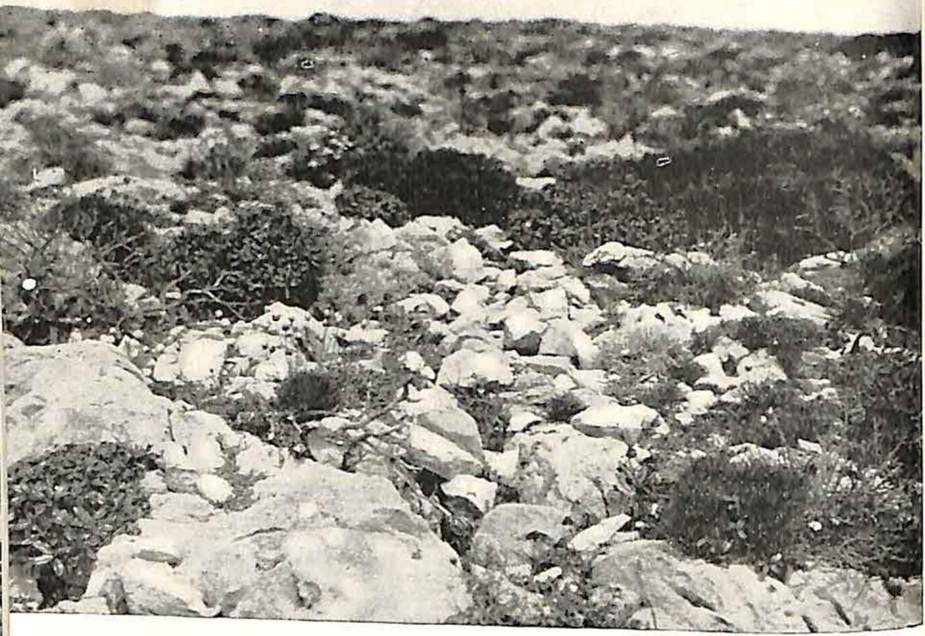
Much of the vegetation in arid regions or " semi-deserts " possesses such means of storing water and is protected from animals in these ways.

Fertile spots (oases) occur in the middle of the deserts. Some of these oases consist merely of a clump of palms surrounding a small spring of water, but others are many hundreds of square miles in area and very fertile. The typical tree is the date-palm.

The animals of the desert are few in number, and they usually have a dull brown colour which exactly matches the sand and prevents them from being seen. The most typical animal is the camel, which is able to go many days without water and which has a broad foot to prevent it from sinking into the sand.

There are two classes of inhabitants in the desert: the wanderers, who move with their camels from place to place; and the settled population of the oases, who devote themselves to growing cereals and rearing cattle, and especially to the cultivation of the date-palm. People living in the desert have little to see except the vast expanses of rocky and sandy waste. They must study the stars to guide them by night, and so we find that the desert has produced philosophical peoples—people who have plenty of time to think and people learned in mathematics and the study of the stars. The wanderers live mainly in tents; but the dwellers in the oases build houses with thick stone walls—to keep them cool—and flat roofs, for there is no need to guard against rain.

(6) *Mediterranean Climate.*—As the sun moves north and south of the Equator during the year, so the main wind belts of the world swing with it. There are parts of the earth between latitudes 30° and 45° which in summer are in the northern part of the trade wind belt, and so are hot and dry like the deserts which adjoin them on the side nearer the Equator. In winter, however, these regions come under the belt of westerly winds, and so enjoy moist, mild winters. In other words, this is the Winter Rain climate. Contrast it with the Monsoon, or Summer Rain, climate, but remember that the Monsoon climate is, on the whole, a much hotter one. The Mediterranean climate is so called because it is found all round the Mediterranean Sea, but it



[Photo : L. D. Stamp

FIG. 155. Mediterranean vegetation of low shrubs in the limestone regions near Cape St. Vincent, Portugal. Soil forms slowly in the Mediterranean climate and so bare rock is often abundant

is also found on the western sides of North and South America, South Africa, and south Australia (*e.g.* Perth, Adelaide, and Melbourne). In the Mediterranean climate, with its mild, moist winter and hot, dry summer, the plants grow mainly during the winter and have to protect themselves against loss of moisture during the hot, dry summer. The vegetation of Mediterranean lands consists chiefly of small trees and shrubs, usually with small leathery leaves well adapted to withstand loss of moisture. Others, such as the olive, have leaves covered with silky hairs ; others, like the vine, have very long roots. The Mediterranean trees are remarkable for their fine, luscious fruit. The most important plant is perhaps the vine, whose fruit (grapes) is made into wine as well as being dried. The well-known fruits include oranges, lemons, peaches, apricots, and pears; there are also nuts, such as the almond, and many others. A large proportion of the tinned fruit now used comes from Mediterranean lands. Much of it comes from the "Mediterranean" region of California, but some comes from other lands of Mediterranean climate. Some of the trees protect themselves from loss of moisture by having a very thick bark. This is of value as the source of cork. Wheat grows well in some Mediterranean lands. In damper or irrigated regions rice may sometimes be grown (as in Italy).

The climate of Mediterranean lands is so favourable that it has harboured many of the great civilizations of the world—Greece and Rome. In summer the people adapt themselves to the climate by working in the cool of the early morning and sleeping during the heat of the day. In Mediterranean countries the houses usually possess thick walls of stone, to keep them cool during the summer, and wide piazzas or verandas for shade.

(7) *Warm Temperate East Coast Climate.*—The Mediterranean climate is found in regions on the western sides of the continents, but on the eastern sides, just outside the tropics, there are sometimes regions having a warm, moist summer and a cool, sometimes dry, winter. This is very like the Monsoon climate, but the temperature throughout the year is lower, as the regions lie outside the tropics. China and eastern Australia, the south-eastern United States, and the coastal regions of Natal are examples, but there is a very considerable difference

between China, with very cold winters, and the other regions. The lands having a warm, temperate climate are forested, but the forests are different from those of monsoon lands, being of deciduous trees, in some areas with pines. There are five separate areas, each having its own special features:

(*a*) *Central and Northern China.*—Central China now has bare hills because the forests have been removed long ago by the people for firewood. The valleys are very densely populated; rice is the grain in the warmer wetter parts. Northern China is too dry for many forests and is largely cultivated, with millet as the chief crop.

(*b*) *South-eastern United States.*—Here "cotton is king" and maize is the food grain. Forests remain in the great swampy valleys and pine forests in the sandy country.

(*c*) *Eastern Australia.*—Here are eucalyptus forests, and this is one of the most fertile parts of the continent.

(*d*) *Natal in South Africa.*—This is also a fertile region, growing maize and sugar.

(*e*) *Southern Brazil.*—The forests here yield valuable timber, and from the leaves of one tree South American tea, or maté, is prepared.

(8) *Cool Temperate Oceanic Climate.*—The Mediterranean regions feel the effect of the rain-bearing westerly (anti-trade) winds during the winter. Lands on the poleward side of those regions are in the westerly wind belt during the whole year. They have rain all the year round, but compared with rain in tropical regions, it is much less. The winters are mild, and the summers cool. This is the climate of north-western Europe (including the British Isles), western Canada, southern

Chile, Tasmania, and New Zealand. On the east of the continents (New England and Manchuria) the winters are much colder, and this is often called the Laurentian or the Cool Temperate East Coast climate. In the monsoon lands, the trees lose their leaves to protect them against the heat of the hot season. In the cool temperate deciduous forests the leaves are lost during the winter to protect the trees against the cold and frost. In America the end of the summer is called the " fall," because it is then that the leaves fall from the trees before the cold of winter comes on. Many of the trees of these forests yield valuable wood—oak, elm, beech, birch, and maple. Forests of this kind formerly clothed a great part of north-western Europe—including England—but have been cut down to make room for agriculture and pastoral industries. Many grains do well in this climate. We must notice that the plants require much less rain than in countries like India, because the sun is less powerful in summer and does not dry up the moisture to the same extent. Eastern England has a rainfall of about 25 inches (roughly the same as the driest parts of the Deccan in India, which are bare and brown half the year), yet the country is clothed with green grass for the whole year. Also we find wheat growing actually better in the drier parts, as in the east of England, than in the wetter parts. In damper regions the grass grows richly and affords fine pasture for cattle. Sheep are found in the drier or hilly parts. On poorer soils and farther north wheat is largely replaced by oats. Barley likes the same climate as wheat, but will grow also in cooler places. Over much of the continent of Europe rye is grown under the same conditions as oats. There is no grain which furnishes such good and nourishing bread as wheat, and the demand for wheat, already enormous, increases yearly amongst the white races. It was noted above that the eastern side of North America, around the St. Lawrence and the New England States, as well as Manchuria on the east of Asia, have much colder winters. In this, the "St. Lawrence type" of climate, mixed forests of deciduous and coniferous trees occur. The climates are healthy and invigorating. Hard work during the whole year is needed in farming; it is not too hot in summer to prevent work during the whole day, and in the winter work is essential to keep warm. So we find the great North European and American civilizations have been fostered by these climates. The houses must be substantially built, for the winters can be very cold and there is no season of the year when rain does not fall.

(9) *Mid-Latitude Grassland or "Temperate" Continental Climate.*—Regions having this climate lie mostly in the same belts as the last—in the westerly wind region—but they are far from the ocean and do not feel the moderating effects of its presence. Consequently the summers are very hot and the winters are very cold—a typical "continental climate." Rain falls mostly in spring and early summer, but it is not heavy. It comes mainly as light showers. In winter a little snow may fall. The great grassland regions of the world where this climate occurs are central Canada and the middle western United States, south Russia and south Siberia. Although this type of climate is found in Australia, there sometimes called the Riverina type. South America (pampas). and South Africa,

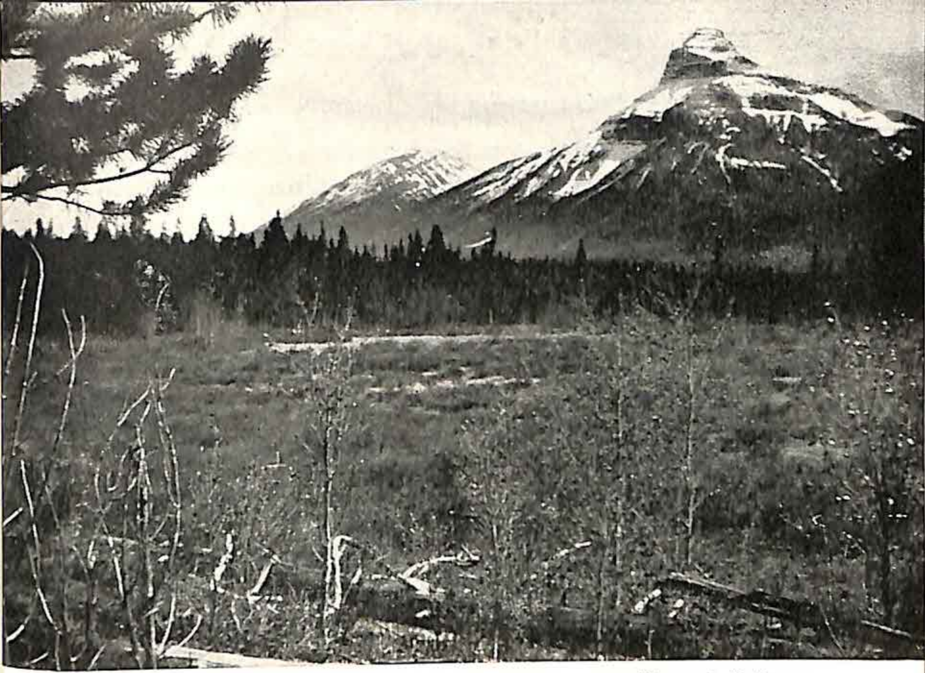


Photo: L. D. Stamp

FIG. 156. In the Coniferous Forest Belt of Canada, near Banff.

In the foreground are some of the small deciduous trees usually found also in coniferous forests and which grow up as "weeds" when the forest trees are cut. In the middle distance is a swampy area devoid of trees.

the extremes of temperature are much less than in the heart of Asia or North America, and snow is rare. The grass in Mid-Latitude Continental climates is usually shorter and less luxuriant than in tropical grasslands, and flourishes even with a rainfall of less than 15 inches. There are vast stretches of these lands without a single tree. The mid-latitude grasslands have received different names in different continents—*steppes* in Asia and Europe, *prairies* in North America, *pampas* in South America, *high veld* in South Africa, and *downland* in Australia—but they are very similar throughout.

In spring the ground is fresh and green and rich with flowers; in summer the sun scorches the grass and the whole country becomes brown; whilst in winter it is often snow-covered and the rivers turned to ice.

As in the tropical grasslands, we find swift-footed grass-eating animals. The horse, ass, and sheep are all typical of these lands.

The primitive inhabitants of the grasslands are nomads. They wander about from place to place with their flocks, for when the grass dries up in one region, a move has to be made to find fresh pasture elsewhere. In richer regions cattle are most important, in drier parts sheep and goats. The people are fine horsemen, for they have to spend much of their time riding, watching the vast flocks and herds. In past ages the grasslands have acted as great "reservoirs" of people. After a series of bad seasons it may be necessary for a great mass of people with their herds and flocks to move bodily in search of fresh lands. In this way great waves of people have swarmed out of the grasslands and settled in surrounding countries. In the centre of Arabia are grasslands from which the Arabs have come out and overwhelmed the lands round about.

In recent times the richer areas of grassland have been rendered suitable for wheat cultivation and farming has largely replaced the pastoral industries.

(10) *Cold Temperate Climate, or Climate of the Coniferous Forests.*—The Cool Temperate Oceanic climate passes gradually into a colder climate where much of the moisture falls as snow and not as rain. This is the region of the coniferous forests and occurs as a great belt across North America, northern

Europe, and northern Asia. The forests are inhabited by animals which have a thick fur to protect them from the bitter cold of winter. So many of the inhabitants are hunters. Naturally logging and timber-working industries are important. The trees are felled during the winter, dragged over the slippery snow, and floated down the rivers when the snows melt.

Similar forests cover large areas of the higher regions of central Europe—there are fine forests on the mountains of Germany and Switzerland and the Carpathians. Wood is abundant and so is the general material for dwellings, which range from the rough log-huts of the North American settlers to the fine wooden "chalets" of Switzerland. The mountainous parts of New Zealand, Tasmania, and south-eastern Australia are sufficiently cold for coniferous forests to grow well. Except in plantations, however, there are no true pine forests in Australia, and the area of such forests in the whole southern hemisphere is very small. In the coniferous forests fire is something very much to be feared, for it destroys the whole forest and is very difficult to check.

(11) *Arctic or Cold Desert Climate.*—Here the winters are very long and very cold, and there is only a very short, sharp summer. The area covered by this climate can be roughly determined by finding the isotherm of 50° F. for July (January in the southern hemisphere). Regions on the poleward side of this line are Arctic or Antarctic. In Arctic and Antarctic regions are vast stretches of desert land—desert not because of the heat, as in the hot deserts, but because of the extreme cold. It is too cold for the growth of trees, and the vegetation consists

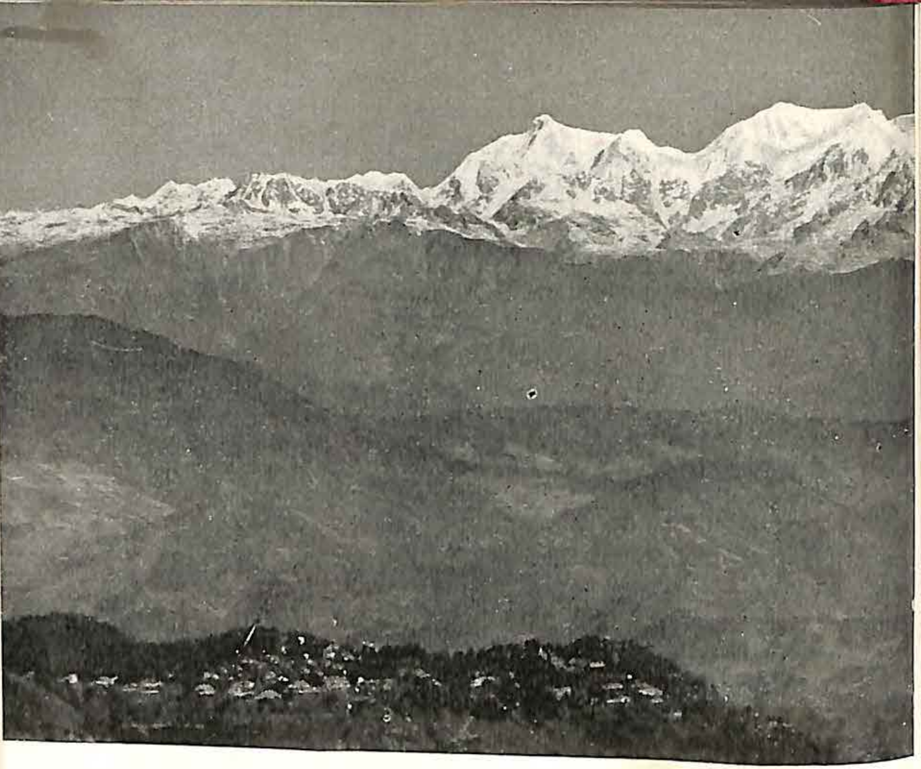


FIG. 157. The Kinchinjunga Massif of the
The highest peak (Kinchinjunga) is 28,225 feet; the snowline is at
amongst coniferous trees at

chiefly of grass, sedge, mosses, lichens and a few dwarf shrubs. The few inhabitants—chiefly Eskimo in Canada—live by hunting the seal, by fishing and by trapping. The soil is permanently frozen a few inches below the surface, and the summer is too short and cool for agriculture. In Europe and Asia the *reindeer* serves as a domestic animal for some herding peoples, of whom the Lapps of Finland, Sweden and Norway are the most famous.

(12) *Alpine Climate*.—The effect of climbing up a mountain is very like going a great distance towards the Poles. The climate changes as we ascend and

[*Photo : Geographical Publications*

Himalayas, seen from Tiger Hill near Darjeeling.
about 20,000 feet. In the left foreground are the houses of Darjeeling
a height of 7,000 to 8,000 feet

gets colder and colder. Near the tops of high mountains it is very cold and there is perpetual snow above the " snow-line." But the climate just below the snow-line is not quite the same as in Arctic or Antarctic lands, because on the mountain-tops the air is very thin. So the climate found on high mountains is usually called the " Alpine " climate, after the Alps. As we ascend the sides of a mountain we often pass through almost the same vegetation zones as if we went on a long journey towards the Poles. Thus in the tropics we should pass from dense tropical forests to evergreen forests, more like those in warm temperate lands. Above these we find coniferous forests; and as we go upwards the trees become smaller and smaller until the "tree limit" is reached. Above this line, or at intervals amongst the forests, are grass-lands or "alpine pastures." These "alps" are important because they afford pasture for sheep and cattle in the summer, but when the winter snows come the animals are driven down into the valleys. This seasonal movement of animals is called "transhumance." Often above the alpine pastures are tracts of alpine vegetation, consisting of scattered clumps of flowering plants. Then the snow-line is reached, above which the snow never melts.

CHAPTER XII

THE SEA

The World Ocean—The average depth of the oceans is nearly 2½ miles—much greater than the average height of the land. The floor of the ocean is much smoother than the surface of the land. Large areas are between 2,000 and 3,000 fathoms (12,000 and 18,000 feet) but there are also great troughs or deeps. Round the land masses there is generally a *continental shelf* where the water is only about 10 to 100 fathoms (60 to 600 feet) deep. From the edge of the continental shelf the level of the sea floor drops rapidly and hence there is support for the idea that the great continental masses are like great islands of lighter rock and that the rocks underlying the ocean are much denser.

The drop from the continental shelf to the ocean floor is often so steep that masses of sediment may slide down the slope and produce within themselves structures which resemble very intense folding and faulting.

Composition of Sea Water.—On an average sea-water contains 35 parts per 1,000 of salts of which common salt (sodium chloride, NaCl) forms 27 parts. When water evaporates the salt is left behind so that enclosed seas where evaporation through the heat of the sun is great and where there are few rivers bringing in fresh water are salter than the open ocean (Mediterranean and Red Seas). Other seas are more nearly fresh (Baltic and Black Seas).

Even in the open ocean there are variations. In the same latitudes as the great deserts, the evaporation is great but rainfall small, so that the surface layers become salter. But salt water is heavier than fresh and so sinks. In some enclosed seas (Black Sea) the lower layers of water are very salt and stagnant, the upper layers comparatively fresh. Besides common salt, the calcium bicarbonate in sea-water is important because it provides the calcium carbonate for the shells and hard parts of molluscs, corals, etc. There are also gases dissolved in sea-water, including the oxygen required by animals and plants, and the carbon dioxide needed by plants. Nitrogen also occurs dissolved in sea-water but in a smaller proportion than in the air.

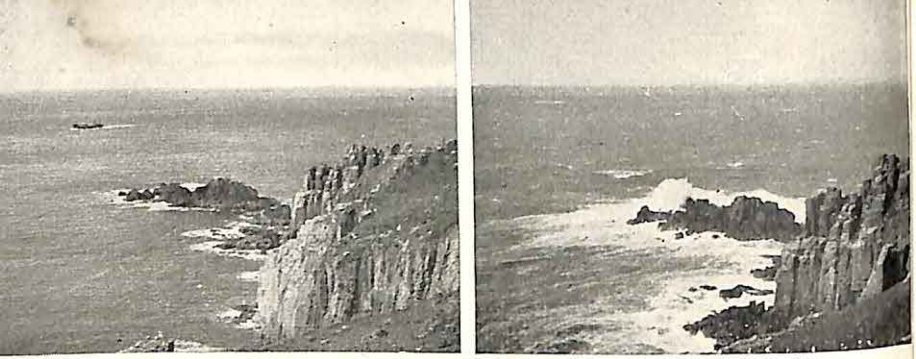
Temperature of the Oceans.—The temperature of the sea is much more uniform than the temperature of the land. Water is heated more slowly than land by the rays of the sun, but also takes longer to cool. Also, the waters of the ocean are constantly moving and mixing.

The temperature of the surface waters of the ocean varies from about 80° at the equator to below freezing point in polar regions (down to about 26° F.). The highest recorded temperatures (in the Persian Gulf and Red Sea) are about 96° F. The temperature varies with the seasons but the range in the open ocean from one part of the year to another is only about 10°. The greatest difference is found where a cold current is important in winter and a warm current in summer as off New York where the range may be 50 degrees. Because water heats much more slowly than land a single day's sunshine is not enough to raise the temperature more than one degree, except in estuaries and on shallow shores. Warm water is lighter than cold, so the warmed water remains at the surface whilst the cold water sinks. Thus there is a uniform temperature all over the floor of the ocean of about 34 degrees. Salt water freezes less readily than fresh, but as soon as ice is formed the ice, of course, floats.

Most of the great icebergs of the polar seas are derived from land ice. They are broken off from glaciers or ice-sheets and float away under the influence of currents. When the sea itself begins to freeze little cakes of ice (pancake ice) appear on the surface. These gradually increase in size and join up to form a continuous sheet (ice-field) which later breaks up under the influence of waves and wind to form pack ice. Sometimes a shelf of ice (ice foot) gradually grows out from land.

Movements of the Oceans.—*Waves* and their destructive action have already been considered. It is only near the shore that the water actually moves forward and back—in the open ocean the movement is simply up and down.

The movement of water from one part of the ocean to another gives rise to *currents*. *Surface currents* are due partly to the wind systems, partly to differences in density; where they flow towards equatorial regions they are cold currents and exercise a cooling influence on the air over them (and so influence the climate of neighbouring lands). Where they flow polewards they form warm currents. In equatorial regions there is often an upwelling of cold water to take the place of that lost by evaporation. This happens off the Pacific Coast of South America and keeps the coast of that continent particularly cool (Humboldt current). There are also bottom currents and



[Photos : L. D. Stamp

FIGS. 158 and 159. Land's End, Cornwall, in fine weather and in stormy weather. Typical Granite Cliffs

currents in or out of enclosed seas—largely determined by evaporation conditions.

The mixing of the air over warm and cold currents produces fogs (as where the cold Labrador Current meets the warm drift from the Gulf Stream off Labrador) and also results in the rapid melting of icebergs and the dropping of their load of débris. Violent storms are also associated with the meeting of currents or, more exactly, with the air masses over the currents (e.g. hurricanes off the coast of Florida following the Gulf Stream).

Tides.—The rising and falling of the surface of the ocean roughly twice a day is called the tide. The water of the Earth is, of course, held to its surface by the force of gravitation, but when a body such as the Earth is rotating on its axis, loose objects including the fluid water, tend to fly away from its surface owing to *centrifugal force*. But the moon is, at the same time, revolving round the Earth and the cause of the tide is really the centrifugal force set up by the Earth and moon round their common centre which is not the same as the centre of the Earth. The moon rises about three-quarters of an hour later

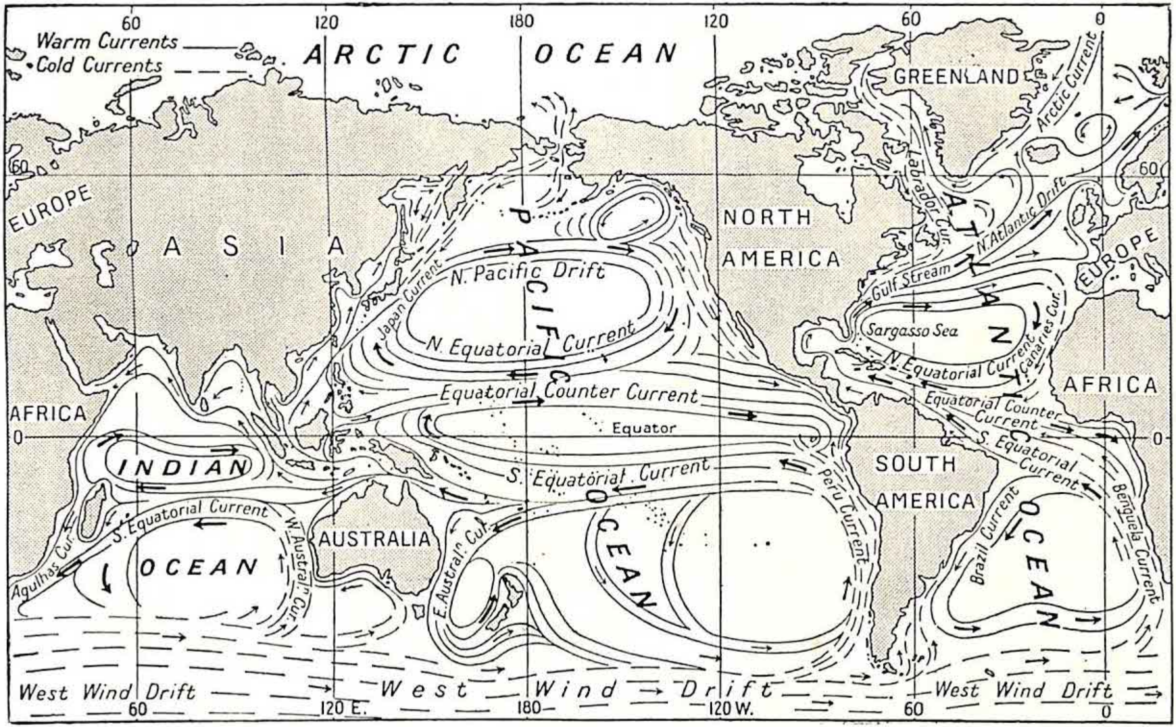


FIG. 160. The Main Ocean Currents

every day and so the high tide of one day is about three-quarters of an hour later than the corresponding tide of the previous day. As there are two tides a day, each is about 12 hours and 22 minutes after the other.

The sun also helps to cause tides. When it is pulling in the same direction as the moon big tides (*spring tides*) result. When it is pulling in opposition, that is at right angles to the moon, small tides (*neap tides*) result.

The effect of the tides is to produce a movement of the water in an ocean basin rather like that produced when a hand-basin of water is disturbed. The water in the centre is almost undisturbed, but it " slops up and down " round the edges. So the effect of the tide is greatest round the shores of the ocean, especially in estuaries. When the water is rising the " flood tide " rushes up estuaries forming a strong tidal current which " ponds back " the fresh water coming down the river. The " ebb tide " is stronger still because it is the combined tidal current and river current. In narrow estuaries the water may rush up as a low wall of water or *bore* (often dangerous to small boats). Water rushing through a narrow channel forms a *race* and where the channel is irregular dangerous *whirlpools* or maelströms may result.

Life in the Ocean.—At 500 fathoms sunlight fails to penetrate and it is quite dark so that most creatures, both animals and plants, live in the shallower parts of the ocean. There are two main groups of animals and plants in the ocean :

(*a*) Those which live floating or swimming on the surface waters. These include the minute animals and plants called collectively plankton. It is these tiny creatures which flourish where there is movement of the water and which form the food of fishes and larger animals.

(*b*) Those which live on or near the bottom (both free, such as flat fish, star fish and molluscs, or fixed, such as corals) and which are particularly important in shallow seas and on the continental shelf.

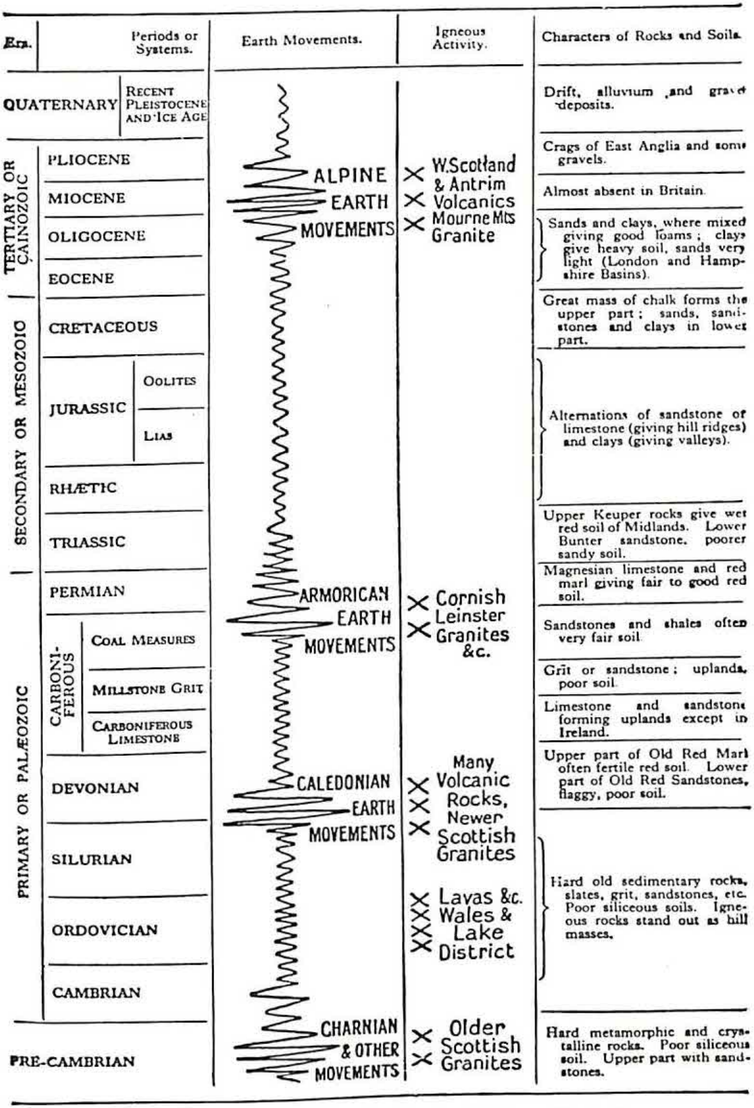
CHAPTER XIII

THE HISTORY OF THE EARTH

Historical Geology.—The present structural and topographical features of the land are the reflection of the long and complicated history of the Earth. It is the purpose of historical geology or stratigraphy to trace the changes which have taken place in the Earth's geography from the dawn of geological time to the present day.

The geologist is loth to measure time in years, but we may be certain that it is not *less* than 100,000,000 years since life first appeared on the surface of the Earth and it may be more like 1,000,000,000 years. Instead of using a time scale of years, the geologist has divided geological time into four or five great eras, and each of those eras into a number of periods. On broad lines the rocks which were laid down in each of those periods can be made to tell the story of the Earth's history. Each period was characterized by its own particular animals and plants, the remains of which were buried in the sedimentary rocks and which can be found to-day as fossils.

The five eras—the Pre-Cambrian (in the rocks of which earliest era no remains of life are commonly found), Primary or Palæozoic, Secondary or Mesozoic, Tertiary or Kainozoic, and finally the Quaternary or Modern era—are the great divisions which the geologist has made in the time scale. Subdivisions, introducing the names commonly



Era.	Periods or Systems.		Earth Movements.	Igneous Activity.	Characters of Rocks and Soils.
QUATERNARY	RECENT PLEISTOCENE AND ICE AGE				Drift, alluvium and gravel deposits.
TERTIARY OR CAINOZOIC	PLIOCENE		ALPINE EARTH MOVEMENTS	× W.Scotland & Antrim × Volcanics × Mourne Mts Granite	Crags of East Anglia and some gravels.
	MIOCENE				Almost absent in Britain.
	OLIGOCENE				Sands and clays, where mixed giving good loams; clays give heavy soil, sands very light (London and Hampshire Basins).
	EOCENE				
SECONDARY OR MESOZOIC	CRETACEOUS				Great mass of chalk forms the upper part; sands, sandstones and clays in lower part.
	JURASSIC	OOLITES			Alternations of sandstone or limestone (giving hill ridges) and clays (giving valleys).
		LIAS			
	RHÆTIC				
	TRIASSIC				Upper Keuper rocks give wet red soil of Midlands. Lower Bunter sandstone, poorer sandy soil.
PRIMARY OR PALÆOZOIC	PERMIAN		ARMORICAN EARTH MOVEMENTS	× Cornish × Leinster Granites &c.	Magnesian limestone and red marl giving fair to good red soil.
	CARBONIFEROUS	COAL MEASURES			Sandstones and shales often very fair soil.
		MILLSTONE GRIT			Grit or sandstone; uplands, poor soil.
		CARBONIFEROUS LIMESTONE			Limestone and sandstone forming uplands except in Ireland.
	DEVONIAN		CALEDONIAN EARTH MOVEMENTS	× × × Many Volcanic Rocks, Newer Scottish Granites	Upper part of Old Red Marl often fertile red soil. Lower part of Old Red Sandstones, flaggy, poor soil.
	SILURIAN			× × × × × Lavas &c. Wales & Lake District	Hard old sedimentary rocks, slates, grit, sandstones, etc. Poor siliceous soils. Igneous rocks stand out as hill masses.
	ORDOVICIAN				
	CAMBRIAN				
PRE-CAMBRIAN			CHARNIAN & OTHER MOVEMENTS	× × Older Scottish Granites	Hard metamorphic and crystalline rocks. Poor siliceous soil. Upper part with sandstones.

FIG. 161. Table of Geological Time Periods

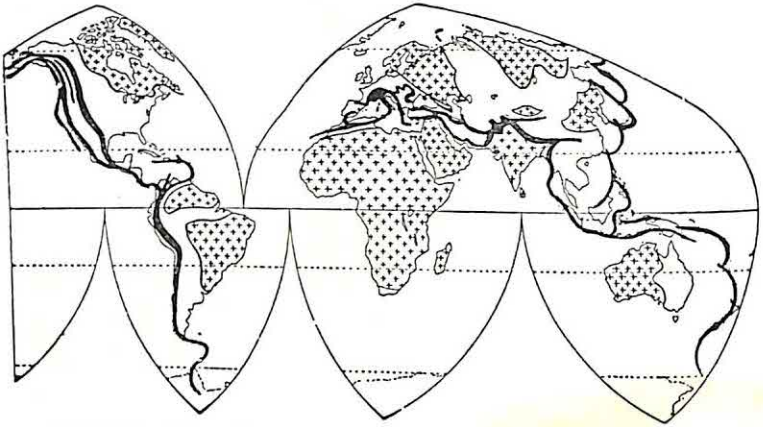
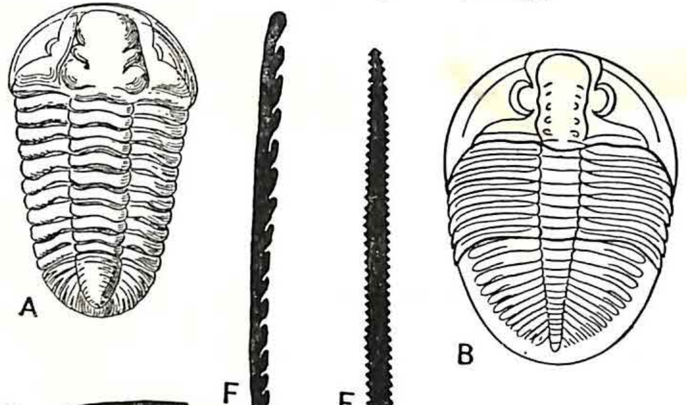


FIG. 162. The main Structural Units of the Earth's Surface

Areas with crosses=blocks of ancient rocks.
Black lines=fold ranges of alpine age.



A—B Trilobites; A *Phacops* (Silurian); B *Ogygia* (Ordovician); C—F Graptolites; C *Didymograptus extensus* (Ordovician; D *Didymograptus murchisoni* (Ordovician); E *Diplograptus* (Ordovician); F *Monograptus* (Silurian).

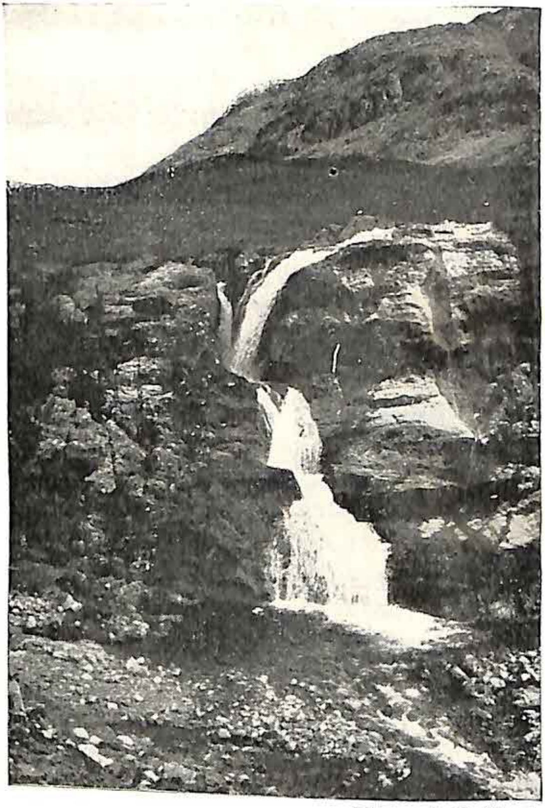
[*After Morley Davies*

FIG. 163. Typical Fossils of the Early Palæozoic Periods

used by both geologists and geographers, are shown in Fig. 161 which also gives details of the main mountain-building movements, the igneous activity in Britain and the rocks mainly found in the British Isles.

Pre-Cambrian Times.—The great masses of crystalline rock on the Earth's surface belong to this period—the chief are shown in Fig. 162. In this dim and distant past there were great mountain-building movements and great outbursts of volcanic activity. The rocks were folded, faulted, metamorphosed and then worn down through long ages to peneplanes. Thus the great areas of Pre-Cambrian are mainly of crystalline rocks and form plains or low plateaus. In the latter part of the period sedimentary rocks were laid down and examples still remaining include the Torridonian Sandstones of Scotland. Peninsular India forms an excellent example of one of the great plateau areas of Pre-Cambrian rocks and the Vindhyan Sandstones on its northern margins represent the sedimentary rocks formed in the later part of the period.

Older Palæozoic Times.—During the first three periods of the Palæozoic era, that is, during the Cambrian, Ordovician and Silurian, the Earth was inhabited almost exclusively by lowly creatures which had not yet attained the dignity of possessing a backbone. During most of this period a land mass lay to the north-west of Scotland and a broad sea-trough ran across the British Isles. Volcanoes were active, especially during the Ordovician, but most of the volcanoes were submarine and poured out their lava on the sea floor ; others were of the explosive type and threw out huge quantities of ashes. So we find in Britain the deposits of these



[*Photo : L. D. Stamp*

FIG. 164. Scenery associated with the Ancient Rocks of the Highlands of Scotland

Note the hanging valley with frost-scarred sides, and the waterfall over hard rocks from the hanging valley.

times are mostly marine—originally clays, silts, sands and coarser rocks—interbedded with lavas and beds of ashes. Most of the sediments have been hardened—the clays have become hard shales and slates, the silts and sands have become sandstones and quartzites, whilst amongst the sediments are found intrusive igneous rocks. So rocks of these ages are usually hard or resistant to weathering and form many of the hill masses of the British Isles. Snowdon and Cader Idris are both built up of lavas of Ordovician age.

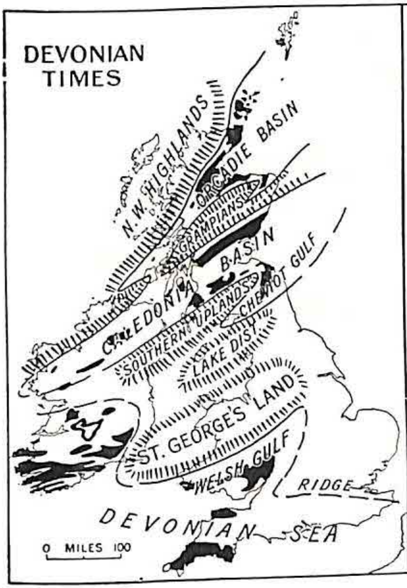


FIG. 165. The Geography of the British Isles in Devonian times

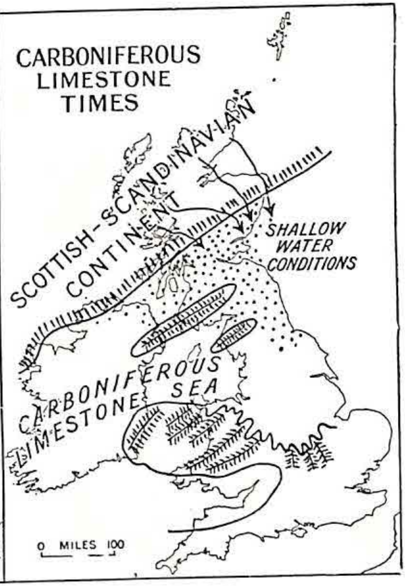


FIG. 166. The Geography of Carboniferous Limestone times

The Caledonian Earth Movements and the Devonian Period.—Towards the close of Silurian times occurred one of the great periods of mountain-building. Because of its importance in Scotland (Caledonia) where the Highlands and the Southern Uplands were formed at first as great mountain chains, this period of folding and faulting is known as the Caledonian. The mountain ranges formed in Britain usually have a trend from north-east to south-west (Caledonian Trend). The earth movements began towards the end of the Silurian and were prolonged into the succeeding Devonian period. The sea trough of Silurian times disappeared and most of the British Isles became a land

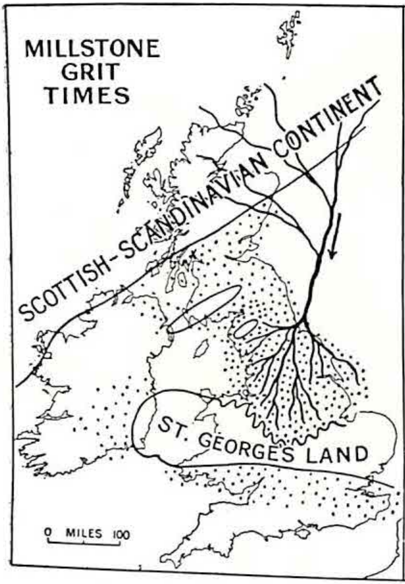


FIG. 167. The Great River Delta of Millstone Grit times

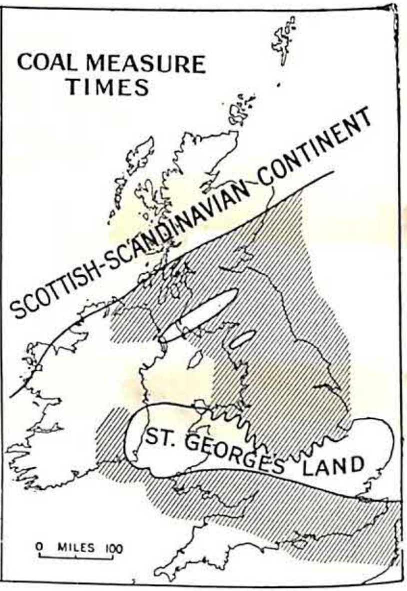


FIG. 168. The Geography of Coal Measure times. The shaded portion shows where the Coal Forests flourished

mass but between the great ridges of mountains were deep valleys or basins. In these torrential streams from the newly formed mountains deposited great thicknesses of coarse conglomerates and sandstones—deposits known as the Old Red Sandstone. In the South of England was a sea in which were deposited the muds, sands, silts, and occasional limestones which formed the Devonian Series of Devon and Cornwall. The few fossils which are found in the Old Red Sandstone are usually of primitive fish and plants. The enormous thickness of many of the Old Red Sandstone deposits testifies to the rapidity with which the Caledonian mountains were worn down by the agents of atmospheric weathering and it may be that the red colour of the rocks reflects desert conditions in the neighbouring mountains.

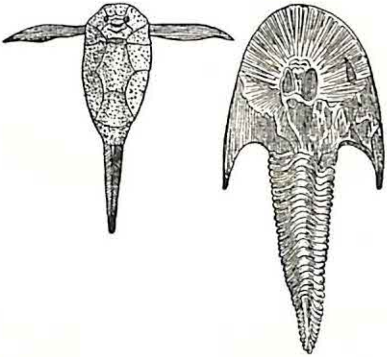
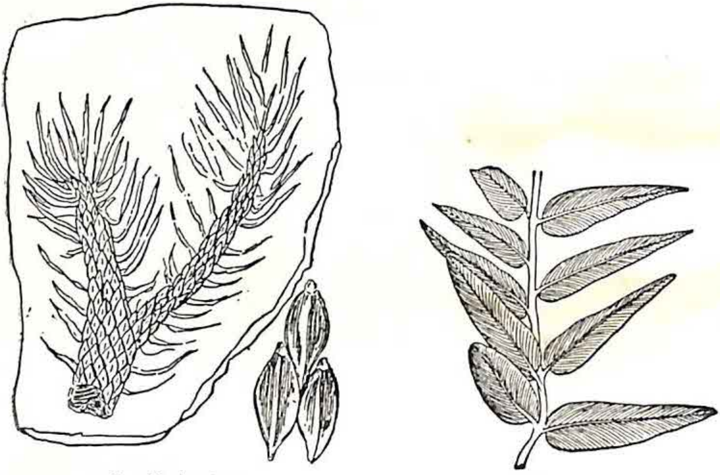


FIG. 169. Early Fishes from the Old Red Sandstone
[*After Jukes-Browne*

Carboniferous Times.—Towards the close of the Devonian Period the mountains were already but mere remnants of their former selves and the commencement of the succeeding period—the

Carboniferous—was marked in Britain by a great invasion by the sea of practically the whole area. The sea flowed into the pre-existing mountain basins, except in the north where the great continent still stretched from Scotland to Scandinavia. Over England and Wales, and much of Ireland, the mountains had been worn down to such an extent that they yielded but little sediment. The clear waters favoured the growth of corals and deposits of limestone were laid down. These Carboniferous Limestones (formerly called Mountain Limestones in Britain because of their association with such mountain or upland areas as the Pennines) occur over great areas. In Scotland, however, there are only thin beds of limestone in great thicknesses of sandstones and shales because here sediments were laid down by rivers from the nearby land.



Lepidodendron *Neuropteris*

FIG. 170. Coal Measure Plants

After Jukes-Browne.

In the middle of the Carboniferous Period a huge river from the north gradually began to overwhelm the British area and to spread its deposits of sand (now the Millstone Grit) as a great delta over central Britain. This delta prepared the way for the very widespread growth of swamp forests whose remains form the coal seams of the present day. The Coal Measures consist of seams of coal separated by thicknesses of shale and sandstone. Underlying each seam is often a bed of clay with roots and the Coal Measure forests have been compared with such swamp forests as the Sundarbans of Bengal (mangrove swamps) except that they consisted of tree-ferns and allied plants long since extinct. Sometimes the *under-clay* is hardened to form a siliceous rock known as *ganister*.

At the time when the Coal Measure rocks were being laid down in Britain a great continent existed in the Southern Hemisphere and in India. This continent has been called Gondwanaland and it is believed that Peninsular India, Western Australia, most of Africa and the Brazilian Plateau form remnants of this old continent. In hollows on the surface swamp forests flourished and so the Coal Measures of India occupy hollows in the old rocks of the plateau.

The Armorican or Altaid Earth Movements.— The close of Coal Measure times is marked in many parts of the world by a great series of mountain-building movements known as the Armorican (Armorica = Brittany in France), Hercynian (Harz Mountains in Germany) Altaid (Altaid Mountains in Central Asia) or sometimes as the Carbo-Permian. In the British Isles these earth movements renewed some of the old Caledonian faults and folds, and gave rise to some new ones having the same trend. But the most typical folds and faults have a new direction—either east to west (Armorican Trend) as in South Wales or north to south (Pennine or Malvernian trend) as in the Pennines and Malvern Hills. Some of the great mountain chains of the heart of Asia date from this period.

Permian and Triassic Times.—As a result of these great earth movements, at the commencement of Permian times Britain was occupied by an important series of mountains, between which were deep desert basins. For this reason the earliest Permian deposits are usually coarse breccias which are of the nature of screes from the newly formed mountains. Beds of coarse conglomerate and boulders, laid down by torrential streams, are also found. One such basin occurred in south-western England. Over Germany, however, there was a large sea or salt water lake (like the Caspian Sea of the present day) which stretched across the North Sea to Northern England. After the early coarse deposits (red Permian marls, etc.) Magnesian Limestone (probably chemically formed) was laid down. There is little doubt that the lands surrounding the Permian lakes and seas were under desert conditions. Most of the Permian Sandstones and marls are red, many contain grains of sand polished by wind action and on the rocks are footprints of reptiles. The Permian and succeeding Triassic deposits are sometimes grouped together as the New Red Sandstone, and the conditions of deposition as well as the rocks are not unlike those of the Old Red Sandstone. Although the Trias forms the first of the Secondary or Mesozoic periods there was little break from the Permian to the Trias. The Trias takes its name from the three-fold division possible in these rocks in Europe—into the lower red Bunter sandstones and pebble beds, the middle Muschelkalk limestone, and the upper red marls (with beds of salt and gypsum formed when the shallow lakes dried up) of the Keuper. The Muschelkalk is absent in Britain, but the red Keuper marls cover much of the Midlands of England and are responsible for much of the red soil there.

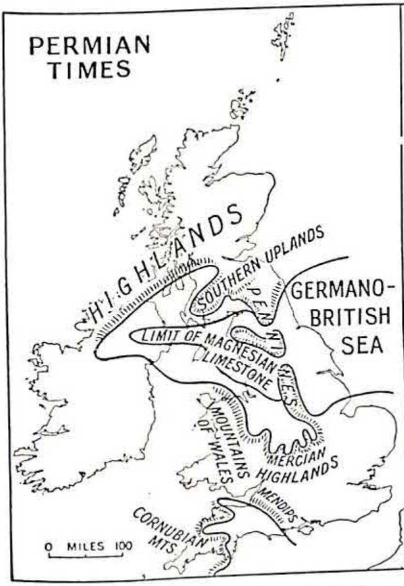


FIG. 171. The Seas and Salt-Lakes of Permian times after the Armorican Earth-Movements

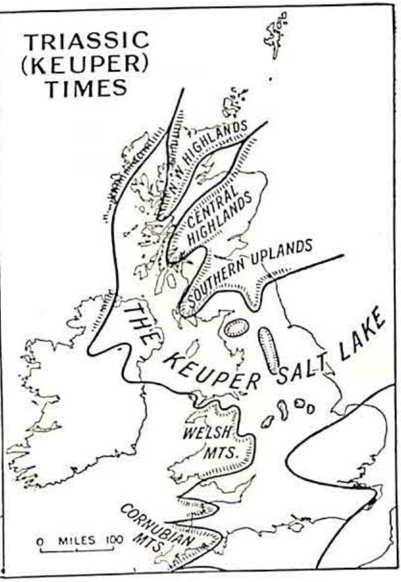
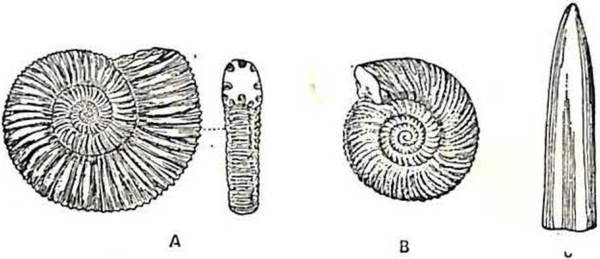


FIG. 172. The Geography of Keuper times

Jurassic Times.—The period which succeeds the Trias is the Rhætic, but rocks of this period are unimportant in Britain. There was an inruption of the sea into the old Triassic basins and vast numbers of fish and other creatures were killed as a result of the change of conditions so that the earliest Rhætic deposits include " bone-beds " built up entirely of the remains of fishes and reptiles. In time the sea covered not only the whole area of the Triassic basins but even overstepped them on to the neighbouring land masses which by this time were worn down so that the material they yielded was more often of the nature of fine sands and muds rather than coarse deposits. The beds of the great Jurassic period can be divided into three groups. The lower Jurassic or Liassic deposits consist of clays and muds, argillaceous limestones or " marlstones " and occasional sands. Enormous numbers of ammonites flourished and these are the dominant marine fossils of the period. There were small folding movements in the Jurassic and the limestones, sandstones, and clays of the Middle Jurassic were laid down in the tranquil waters of basins more or less cut off from one another. The conditions were particularly suitable for the accumulation of the well-known oolitic limestones—the freestones of Bath. In the Upper Jurassic, on the other hand,



Ammonites (A—B), and Belemnites (C)

FIG. 173. Jurassic Fossils [*After Jukes-Browne*

clays and sands again predominate though the famous Portland oolitic limestone is of this age. The difference between the soft or easily eroded clays and the more resistant sandstones or limestones by which they are separated has given rise to the well known "Scarplands" and "clay-vales" of south-eastern England.

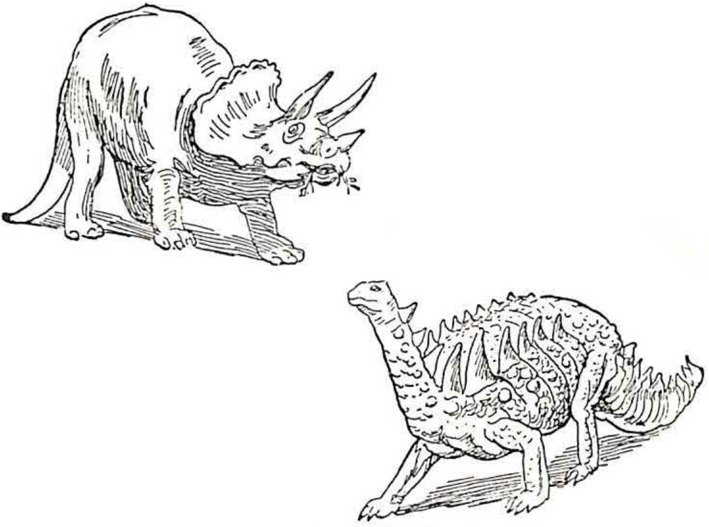


FIG. 174. Jurassic Reptiles

At the close of the Jurassic period the sea retreated and left a great lake in south-eastern England—the Wealden Lake around which roamed the famous giant reptiles or iguanodons—but the sea persisted in north-eastern England.

Cretaceous Times.—In due course the Wealden Lake basin was invaded by the sea and the earlier marine deposits of the Cretaceous period are sands and clays. There had been no important mountain-building movements since the Armorican and so the lands surrounding the Cretaceous seas were low and yielded little sediment. After the formation of the Greensands and the Gault the surface subsided and the waters of the Cretaceous seas became deeper and very clear. Conditions favoured the deposition of the most famous of all British rocks—the pure white limestone known as the Chalk. It used to be thought that the chalk, like the Atlantic " oozes " of the present day, was formed in very deep water, but it is now believed that the water, though clear and free from sediment, was not very deep. It is believed by many that the peneplanation of the old rocks of Wales, and probably also of part of the Highlands and Southern uplands of Scotland was the work of the waves of the Chalk Sea.

In Cretaceous times there occurred in India the great outburst of volcanic activity which covered 200,000 square miles with the lavas of the Deccan. The outpouring of these sheets of liquid rock continued into Tertiary times. It is believed that the great granite masses of Southern Burma and Malaya (with which the tin deposits are associated) are of the same age.

Tertiary Times and the Alpine Earth Movements.—Although no great mountain-building movements occurred in Europe at the end of the Cretaceous, the geography of early Tertiary, times shows a great change. There was actually a considerable lapse of time between the deposition of the highest chalk and the succeeding Tertiary beds. The earliest of the Tertiary deposits in Britain belong to the Eocene, and Britain began to assume some of its chief geographical features of the present day. The whole seems to have risen and only the south-east was covered by a sea. Into this sea there emptied one or more great rivers coming from the west. The rivers laid down sands, mottled clays, and other deposits of predominantly "continental" origin in the western parts of what we call the Hampshire and London Basins, whilst towards the east of these

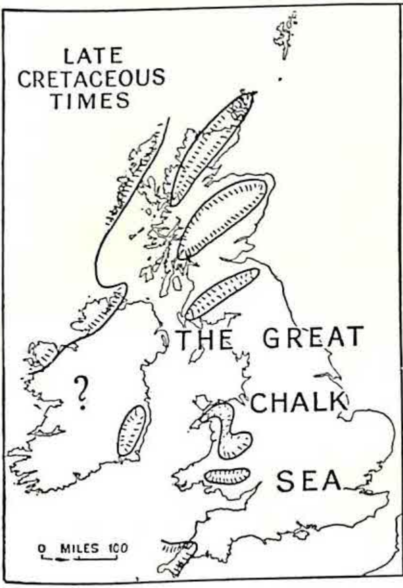


FIG. 175. A Map Showing the Area *Probably* Covered by the Chalk Sea

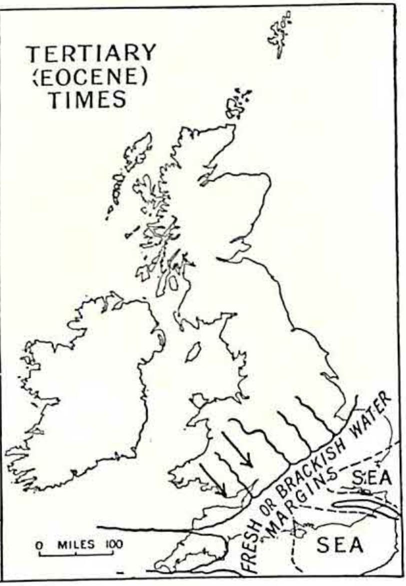


FIG. 176. The Geography of Early Tertiary Times.

same basins there were being deposited clays or muds and sands containing marine fossils. It was during the Eocene period that there occurred some of the earlier earth tremors which were gradually to increase in strength and to culminate in those earth-building movements which were the most important of all in determining the present physical features of the Earth's surface—the Alpine earth movements. It seems probably that the famous Wealden dome commenced to rise in the early Eocene—perhaps even before. In the same way the great storm which gave rise to the Himalayas began by small movements even before the Tertiary. It is probable that the Arakan Yoma mountains began to rise even before the Eocene and cut off the Assam basin from the Burmese basin.

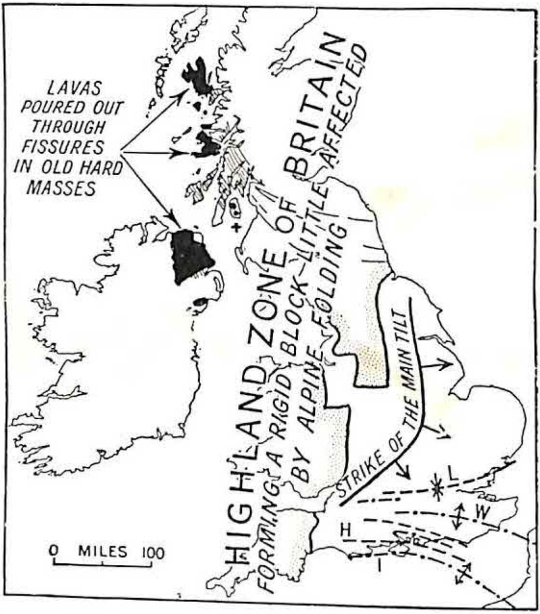
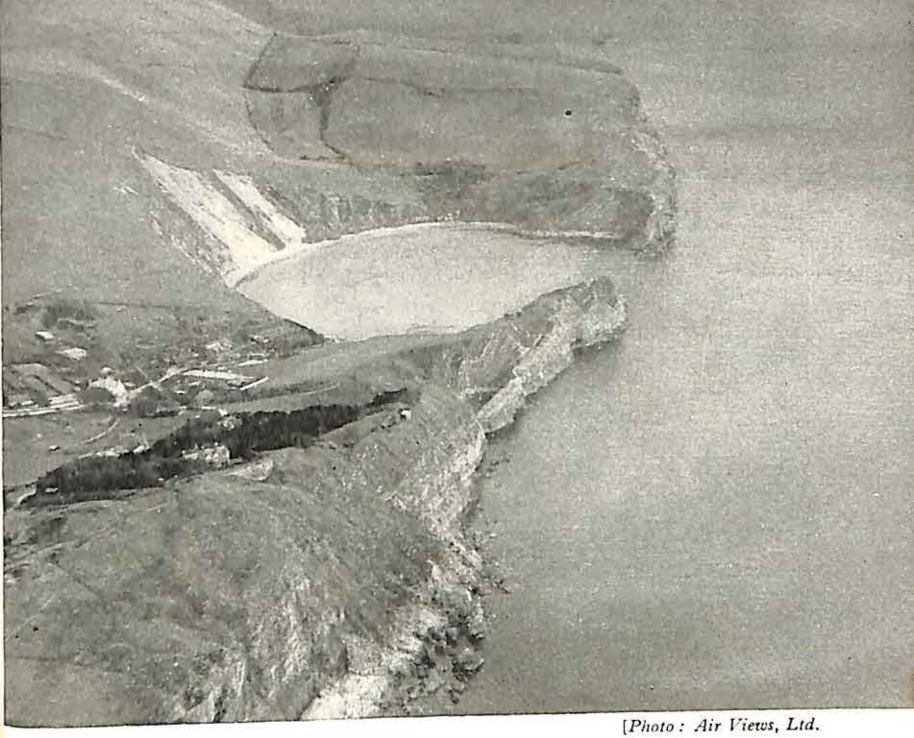

LAVAS POURED OUT THROUGH FISSURES IN OLD HARD MASSES
HIGHLAND ZONE OF BRITAIN
FORMING A RIGID BLOCK—LITTLE AFFECTED BY ALPINE FOLDING
STRIKE OF THE MAIN TILT
L
W
H
I
0 MILES 100

FIG. 177. The Structural Elements of the British Isles

The arrows show the dips of the rocks. The fine black lines in the north are dykes of igneous rock filling cracks.

The succeeding Oligocene period has left little trace in Britain, but great thicknesses of beds of this age were laid down in the Alpine and Himalayan



[*Photo : Air Views, Ltd.*

FIG. 178. Lulworth Cove, Dorset

The sea has cut through the rampart formed by hard Jurassic limestones (which can be seen to be highly folded by Alpine earth movements) and has cut out a circular bay in the soft clays behind (Lower Cretaceous). The further advance of the sea is stopped by the more resistant chalk, which gives rise to the rolling downlands on the left. Notice the white chalk cliffs.

regions and in the near-by basins such as Burma. Towards the end of the Oligocene and during the succeeding Miocene the great Alpine storm broke. This great period of earth-building movements caused the formation of all the " young " mountain chains—the Alps, Carpathians, Caucasus, Atlas, Himalayas, Rockies, Andes, etc. The British Isles were comparatively little affected, since earlier folding movements had converted the north and north-west into great "stable blocks" too rigid to be further folded. The parts of Britain most affected were the south-east—nearest the Alpine area—and so the folds of the Isle of Purbeck and Isle of Wight as well as the main folding of the Weald and London Basin are of this age. The older rocks of north-western or Highland Britain were not folded but were cracked and fissured. Through the fissures came great flows of lava, forming the lava plateaus of Antrim in Northern Ireland and many parts of Western Scotland. Some granitic intrusions, such as the Mourne Mountains of Ireland, belong to the same period. The succeeding Pliocene period saw Britain taking on very much the form that it has at the present day. The Pliocene sea lingered in what is now the London Basin and later retreated further north and occupied what is now the North Sea. Thus Pliocene deposits in Britain are found almost entirely in the London Basin and and East Anglia.

In other parts of the world the Alpine earth movements went on through the Miocene and Pliocene periods. On the margins of the Himalayas and in Burma, for example, the latest Pliocene deposits are highly folded. Much volcanic activity was associated with the later stages, and most of the world's active volcanoes are those which have remained from the Alpine period.

The Great Ice Age.—One of the most important episodes in the earth's history is one of the latest. At the height of the Glacial Period or Great Ice Age the northern half of Europe, including the British Isles as far south as the Thames, was covered by great ice sheets. Some of these were local and had their centres on such upland areas as the

Highlands of Scotland, Southern Uplands, the Lake District, and the mountains of North Wales and Ireland, but other parts of the British Isles, particularly the east, were affected by the enormous ice sheet which had its centre over Scandinavia and stretched over the North Sea and much of the Great European Plain.

The Great Ice Age had many important effects. It removed much of the soil previously formed and loose rock from upland areas and smoothed the hard old rocks so exposed. Thus glaciated areas of this sort are usually poor, being almost devoid of soil. Tongues of ice scooped out hollows in pre-existing valleys and gave the typical glacial lakes and U-shaped valleys. Of the low-lying areas great stretches were covered with glacial deposits which thus form

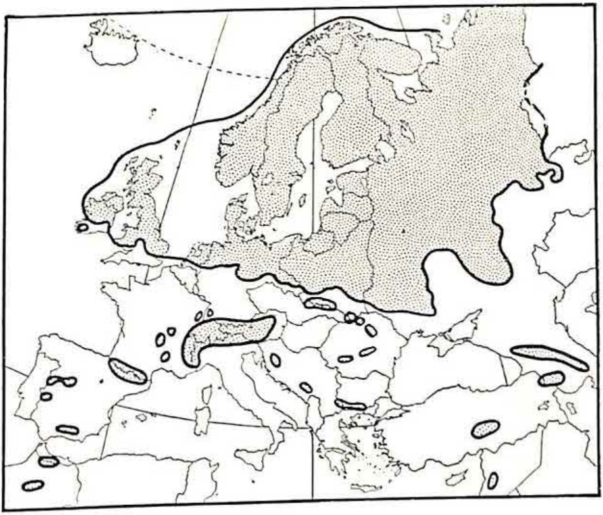


FIG. 179. The Great Ice Age in Europe

The dotted area is that covered by ice at the period of its greatest extension

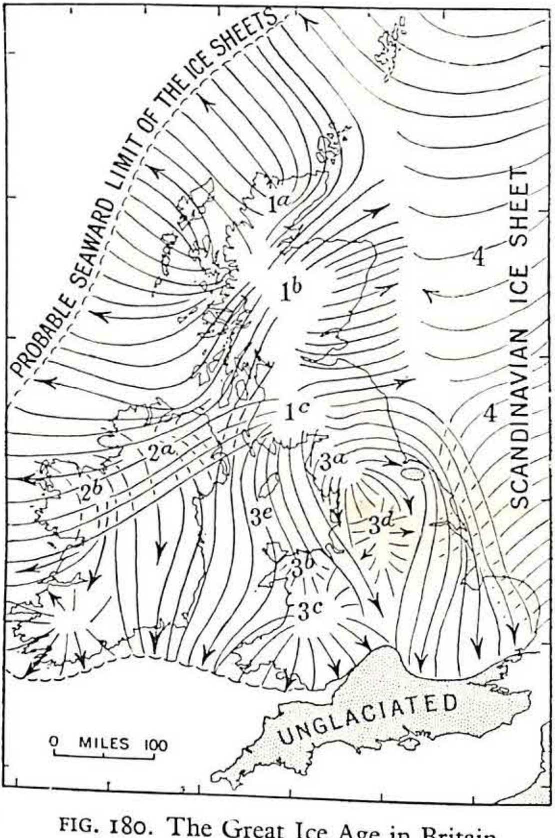
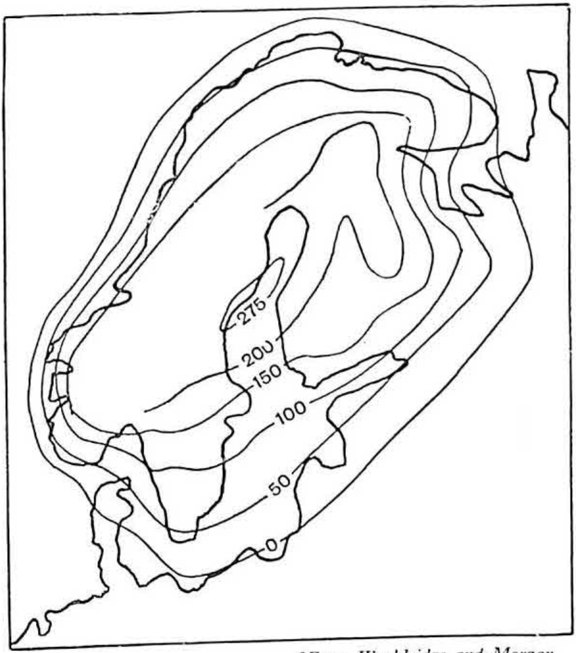


FIG. 180. The Great Ice Age in Britain

The arrows show the direction of movement of the ice sheets. The local ice-caps are: 1*a* North-West Highlands; 1*b* Grampians; 1*c* Southern Uplands; 2*a* and 2*b* Northern Ireland; 3*a* Lake District; 3*b* North Wales; 3*c* Central Wales; 3*d* Southern Pennines; 3*e* Irish Sea.

the basal material for the soils of much of lowland Britain. Then the glaciers profoundly altered the drainage.

Since the retreat of the ice sheets from the British Isles there have been several fluctuations in the level of the sea and land. Over Scandinavia the enormous weight of the ice-cap actually depressed the land many hundreds of feet; when the ice melted, the land rose and in places is still rising. In other cases submerged forests round the coasts of Britain show that the land has sunk in places.



[*From Wooldridge and Morgan*

FIG. 181. The Rise of the Scandinavian Peninsula (in Metres) after the Removal of the Ice

Undoubtedly during the Great Ice Age the glaciers of the Himalayas were much larger than at present though such parts of the tropics as India were not themselves covered with ice sheets. In Central Asia the glaciers have been gradually melting for a long time and now there is less water from melting ice than there used to be and so the country (as in the Tarim Basin) appears to be drying up.

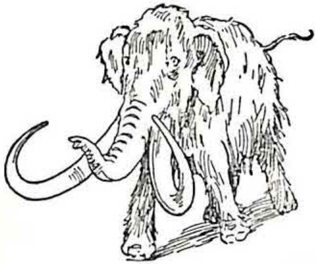


FIG. 182. The Mammoth, which flourished during the Great Ice Age

CHAPTER XIV

THE PHYSIOGRAPHY OF THE BRITISH ISLES

Highland and Lowland Britain.—In the last chapter, by considering the changes in the distribution of land and water over successive geological periods, we traced the evolution of the physical features of these islands. The island of Britain is broadly divisible into two parts: a Highland Zone on the north and west, a Lowland Zone on the south and east. The line which separates these two divisions cuts across the country, following a somewhat irregular course, from the mouth of the River Exe in the south-west to near the mouth of the River Tees in the north-east. It is roughly the line separating the outcrops of the Palæozoic rocks on the one hand and the Mesozoic and Tertiary rocks on the other. To the north and west of the line lie the remnants of the great mountain chains which were built up by successive earth-building movements of Pre-Cambrian, Siluro-Devonian, and Carbo-Permian times. The mountains are, for the most part, but remnants of their former mighty selves, but they still comprise the

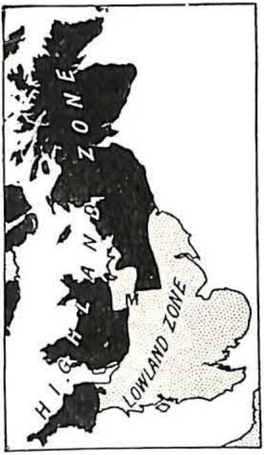


FIG. 183. The Highland and Lowland Zones of Britain

major mountain and hill masses of Britain Generally the most ancient masses are those which occur, as in the case of the Highlands of Scotland, farthest to the north-west. Naturally the margins of the ancient rocks are not infrequently covered by strata of later ages.

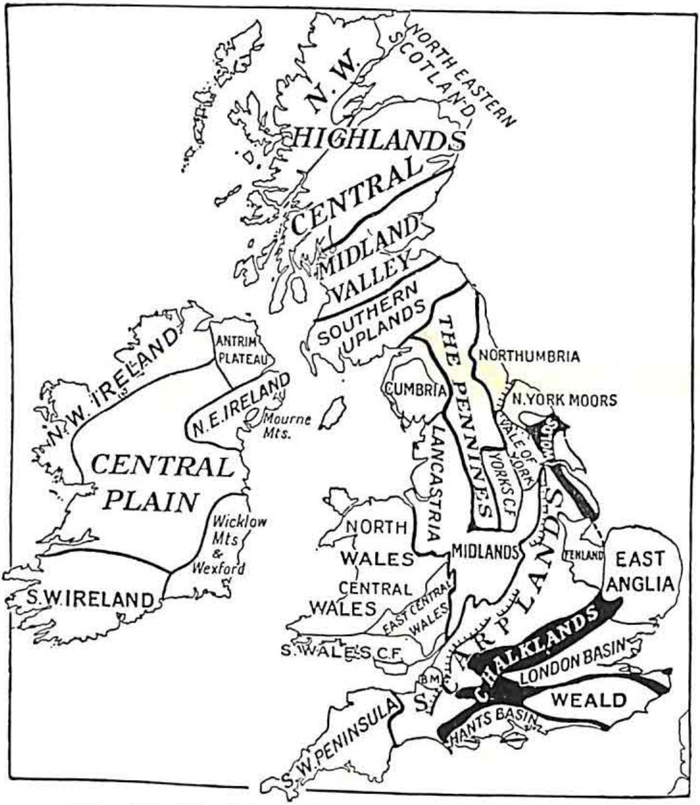


FIG. 184. The Physical Regions of the British Isles

To the south and east of the line are first the broad plains or low-lying plateaus, built up mainly of Triassic rocks, which constitute the Midlands of

England. Not infrequently small remnants of the ancient mountains stand up as islands in the midst of these plains of younger rocks. Farther southwards and eastwards the Midland plains give place to the scarplands of England. It is possible to draw another line across England, again somewhat irregularly, from the Dorset coast to the north Yorkshire coast. To the south and east of this line lie low ridges, separated by shallow valleys, which mark respectively the outcrop of the harder or more resistant, and softer or less resistant beds of the geological sequence from the early Jurassic onwards. Like the Triassic rocks of the Midlands, these rocks rest upon an ancient platform which lies buried beneath them at a greater or less depth. Sometimes, as for example under London, the ancient platform is within a thousand feet of the surface. At other times the Palæozoic platform lies at such a depth that the full thickness of the overlying beds has never been penetrated by the boring tools of the well-engineer. The Jurassic and later rocks have themselves been gently tilted, usually towards the south-east, by the Alpine system of earth movements ; but it is only in the extreme south that there are signs of severe folding.

The Highlands of Scotland.—The Highlands of Scotland are built up for the most part of great masses of ancient metamorphic or crystalline rocks—gneisses, schists, slates, and quartzites. Some of the folding took place in Pre-Cambrian times, and probably some of the great intrusions of granite and of other rocks are of the same date. The great period of earth movements which determined the major structures of the Scottish Highlands was, however, the Caledonian, or Siluro-Devonian.

These movements gave rise to great mountain chains with a general trend from south-west to north-east, and this is still the dominant "grain" of the country. Between the great mountain chains were the deep basins in which the deposits of the Old Red Sandstone were laid down. Much of the Highlands of Scotland has probably remained land from those very remote ages to the present day, and consequently sub-ærial denudation has gone on almost continuously, culminating with the work of the great ice caps which covered Scotland during the last glacial epoch. As a result, the Highlands of Scotland are not now rugged mountains but hills and mountains with rounded outlines which are the results of long ages of sub-aerial denudation and the work of ice. On the whole, the Highlands form an irregularly surfaced plateau with its greatest elevation along the western margin, sloping on the whole towards the east. The plateau surface has in general an average elevation of between 2,000 and 3,000 feet; some of the higher points often marking the outcrops of granite. The highest points may reach over 4,000 feet, and included amongst them is Ben Nevis, the highest mountain in the British Isles, of 4,400 feet. The Scottish Highlands are divided into the North-West Highlands and the Central Highlands or Grampians by the great cleft of Glen More. The North-West Highlands are by far the more rugged and the grander, and meet the Atlantic Ocean in the intricate fiorded and island-bounded coast of western Scotland. It seems possible that the Alpine earth movements, being unable to fold the old stable block, tended to fracture it instead, and the belts of crushed rock which were formed along the fractures have been more easily excavated by rivers and by ice, and by the waves of the ocean, thus giving rise to the fiords with their remarkable rectangular bends. Through some of the major cracks, too, igneous rocks of Tertiary age have welled up and give rise to the marked lava plateaus of Skye and some other parts of the western coast of Scotland, comparable in character to those found in Iceland. The Old Red Sandstone, originally deposited in valleys, still occurs in valley or lowland situations.

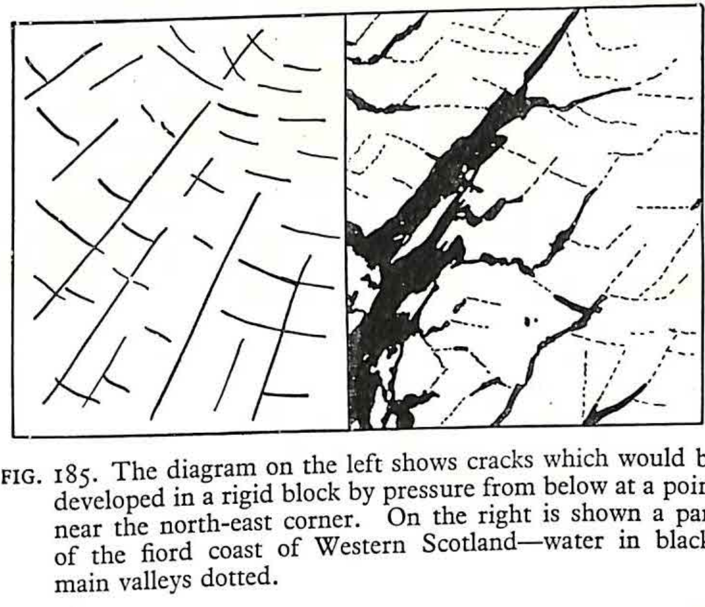


FIG. 185. The diagram on the left shows cracks which would be developed in a rigid block by pressure from below at a point near the north-east corner. On the right is shown a part of the fiord coast of Western Scotland—water in black, main valleys dotted.

The ancient rocks of the Highlands generally give rise to poor soils, whilst much of the soil which must previously have been formed has been swept away from the higher areas by the ice sheets of the glacial epoch. The tracts occurring on the Old Red Sandstone are, on the whole, more fertile. The same is true of the lower eastern margins of the ancient rocks themselves, as for example in the area known as the Buchan Plateau. Geographically, the eastern margins, whether they are on the ancient rocks or on Old Red Sandstone, are somewhat distinct from the main mass of the Highlands and are frequently considered as a separate region under the title of North-Eastern Scotland. The Orkney Islands form a detached portion of this area, whilst the Shetland Islands, farther north, resemble more closely the central part of the Highlands themselves. The southern limit of the Highlands of Scotland is remarkably well defined by the great Highland boundary fault, actually a succession of faults, which runs across the country with a Caledonian trend, from the mouth of the Clyde to the east coast in the neighbourhood of Stonehaven. The faults were initiated at the same time as the Caledonian earth movements, but intermittent movements along them have undoubtedly occurred from that time until the present.

The Southern Uplands.—The Southern Uplands consist of the denuded remains of a great mountain chain of Siluro-Devonian age and which runs across the south of Scotland from the south-west to the north-east, that is with a characteristically Caledonian trend. There is, however, a marked difference between the Southern Uplands and the Highlands. The rocks of which the Southern Uplands consist are sediments, mainly of Ordovician and Silurian age, very highly folded. In the south-west, particularly in Galloway, there are large granitic intrusions, but ancient metamorphic rocks, such as those constituting the greater part of the Highlands, are absent.

Consequently all the higher parts of the Southern Uplands are formed of moorland country with rounded outlines, passing on lower ground in the east, particularly in the Tweed basin, to quiet rolling pastoral and well-wooded country. In the south-west, cutting across the main mass of the Southern Uplands, are the well-known dales. These dales are comparatively straight clefts running from north-north-west to south-south-east and afford important routeways. Fringing the Southern Uplands, along the shores of the Irish Sea, are stretches of low ground, occupied by pasture. The northern limit of the Southern Uplands is formed by a great zone of faulting, comparable in character to the fault-line which bounds the Highlands, though not giving rise to such a marked feature.

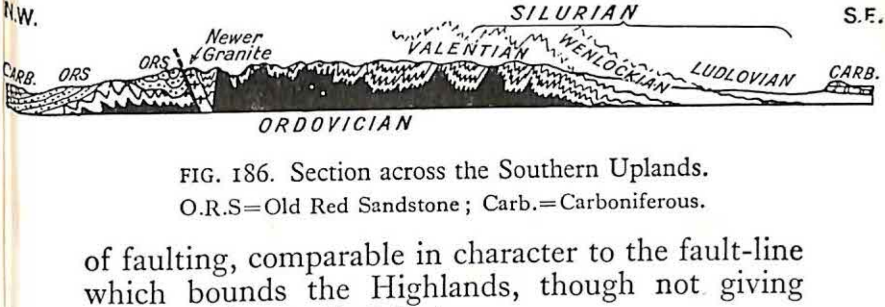


FIG. 186. Section across the Southern Uplands.
O.R.S=Old Red Sandstone; Carb.=Carboniferous.

The Central Lowlands, or Midland Valley, of Scotland.—Lying between the Highlands on the north and the Southern Uplands on the south is the great rift valley which forms central Scotland. Initiated by the Caledonian earth movements it was a basin of deposition of the Old Red Sandstone, and was later occupied by a shallow arm of the Carboniferous sea, so shallow that at an early stage it was suitable for the growth of the swamp forests which have left their traces at the present day in seams of coal. At the same period volcanic activity was rife, and as a general result at the present day neither the topography nor the geology of the Midland Valley of Scotland can be described as simple. It is only in the broadest possible sense a valley. It is possible to distinguish a northern fringing corridor or broad valley, then a line of volcanic hills, then the central lowlands wherein lie the great Lanarkshire or Central Coalfield and the Midlothian–Fifeshire Coalfield, then a line of hills along the south and an ill-defined valley separating them in turn from the Southern Uplands. These sub-divisions of the valley and their correlation with the geology may be seen in Figs. 187 and 188.

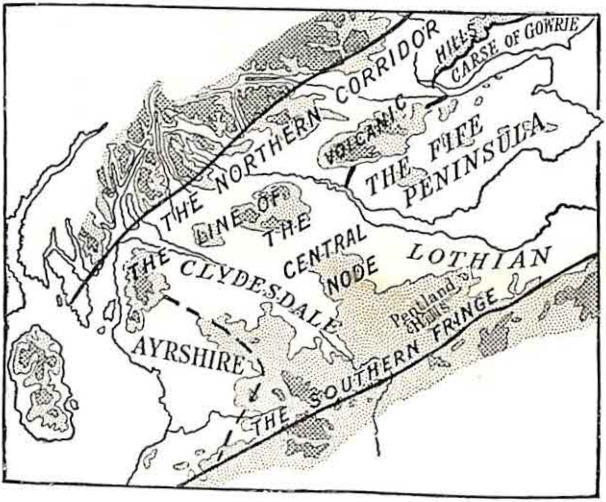


FIG. 187. Sub-regions of the Midland Valley

The Lake District or Cumbria.—The folding of the mountains which now make up the Lake District probably commenced even as early as Ordovician times, but the main earth movements responsible for the formation of the group were, like those of the Southern Uplands and of the Highlands, the great Caledonian movements. Consequently the geological structures in the main part of the Lake District have a trend from south-west to north-east, and there is no doubt that originally the Isle of Man

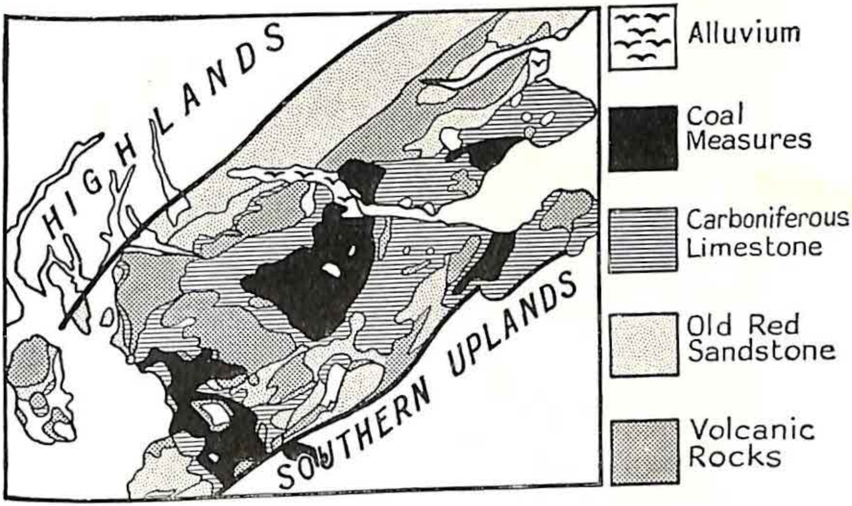


FIG. 188. The geology of the Midland Valley

Note the separation of the Ayrshire and Central coal basins by an axis of uplift (N.W—S.E.) and the separation of the Central and Midlothian by another axis (S.W.—N.E.).

and the Lake District were joined and formed a single great chain of mountains. But the mountains suffered great denudation, and at a later stage the waters of the Carboniferous sea washed round them and may even have submerged the whole, so that Carboniferous Limestone was deposited on the flanks of the old central core. At a later stage—probably during the Alpine earth movements—a local uplift occurred in the heart of the Lake District. The uplift may have been due to a great mass of molten material in the lower layers of the earth's crust attempting, without success, to force its way to the earth's surface. Whatever its cause, the uplift has resulted in the two great features of the area of the present day. These two features are the occurrence of the main mass of ancient rocks in the heart of the area, surrounded by younger rocks which in general dip away from the centre core. In the second place the uplift seems to have been responsible for the initiation of one of the most remarkable examples of radial drainage which is known. The well-known lakes of the Lake District radiate like

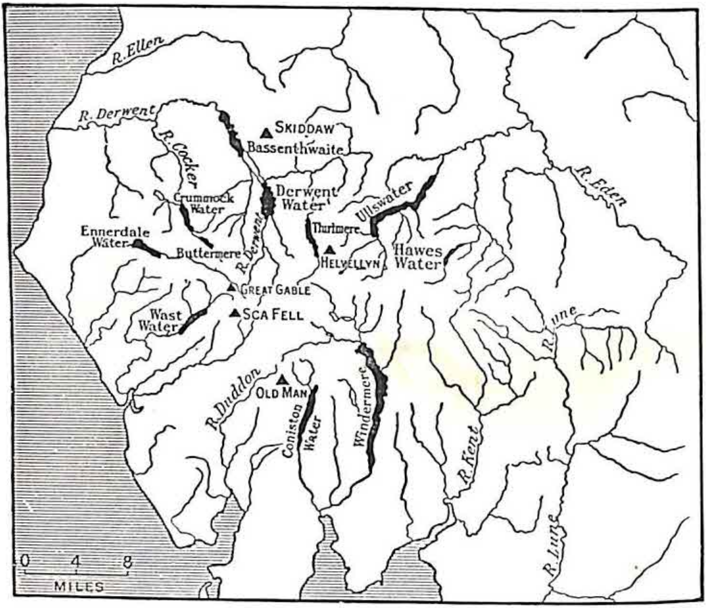


FIG. 189. The radial drainage of the Lake District.

the spokes of a wheel from a central hub, and it is because this uplift took place at a comparatively late stage that the forces of denudation are still active Thus the Lake District has some of the finest rock scenery and, despite their relatively low altitude, rugged mountains in the British Isles. Geographically there is a remarkable contrast between the area of ancient rocks in the heart of the Lake District and the surrounding ring of younger strata. Only on the south-east do the Shap Fells connect the Lake District proper with the hill masses of the Pennines.

Wales or the Welsh Massif.—The Welsh massif may be considered as embracing all the hill masses which lie to the west of the English Midlands, excluding only the southern part of the county of Glamorgan, which actually ought to be considered as part of the English plain or scarplands. The western margins can be clearly traced from any physical map. In the north the Welsh hills abut quite abruptly on the Cheshire and north Shropshire plain; along the margin lies the North Wales Coalfield. The hills of central and southern Shropshire belong structurally to the Welsh massif, and from central Shropshire southwards to the mouth of the Severn the eastern limit is defined by the line of hills running southwards from the Wrekin in Shropshire to the Abberley Hills and the Malvern Hills. The oldest part of the Welsh massif is in the north-west, where the ancient crystalline rocks of the isle of Anglesey underwent folding in Pre-Cambrian times. The folding was continued during the Caledonian earth movements and post-Carboniferous foldings followed along the same lines, so that there are narrow bands of Carboniferous Limestone pinched in amongst the ancient rocks. The whole of Anglesey, as the result of later denudation, has been worn down to a low plateau, almost to a sea-level plain, and its complicated geological history is scarcely suggested by the somewhat uninteresting topography of the island. The mainland of north Wales is still, on the other hand, a land of rugged mountains. On the whole the grain of the country is from south-west to north-east, indicating that the mountains owe their origin in the main to the Caledonian earth movements. The rocks involved in the folding are, for the most part, Older Palæozoic, but the mountains owe their rugged character of to-day to the large masses of lava which were extruded as well as to other igneous masses which were intruded into the rocks before and during the folding. The igneous rocks have proved themselves more resistant to weathering, and most of the higher points, such for example as Snowdon and Cader Idris, mark the outcrop of one or more masses of igneous rock. Passing from north into central Wales, the igneous masses become less numerous, and this is one reason for the less rugged topography of central Wales. The age of the folding of the rocks, too, becomes successively younger as one goes towards the south. Coal Measures were laid down over a huge area in South Wales, and at the end of the Carboniferous period were folded by the Carbo-Permian or Armorican earth movements. These earth movements resulted in folds with an east-west trend, thus causing the great coal basin of the South Wales Coalfield. It would seem that the Armorican earth movements were unable to fold the already highly complicated and hardened masses of North Wales, and that the earth-building waves broke against this resistant mass both along its southern and eastern sides. Thus there are east-west folds in the south, but north-south folds in the east. Some of the latter are remarkably sharp, and one forms that curious line of hills, the Malvern Hills. The Malvern Hills folds are typical of the group with a north-south trend which is referred to as the Malvernian group. Where the north-south and east-west folds cross, small nodes and basins were formed of which the Forest of Dean coalfield is an excellent example.

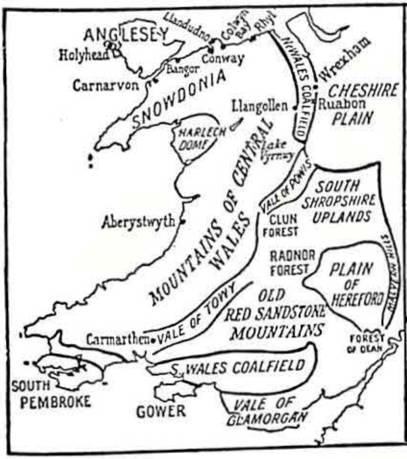


FIG. 190. Wales, showing a division into physiographic regions

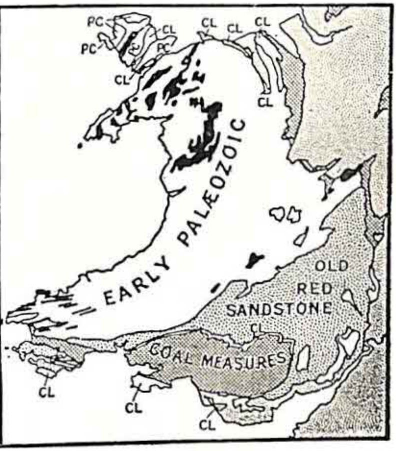


FIG. 191. Geological map of Wales

Black = igneous rocks; PC = Pre-Cambrian; CL = Carboniferous Limestone.

It will be seen that a triangular space remains between the east-west Carboniferous folds of South

Wales, the north-south Malvernian folds of the eastern margin, and the south-west to north-east Caledonian folds of central Wales. This triangular space is occupied mainly by rocks of Old Red Sandstone age. Where the rocks consist mainly of hard red sandstones and conglomerates, they give rise to high moorland country such as that of the Brecon Beacons, including indeed some of the wildest moorland country in the whole of the British Isles. Where the Old Red Sandstone consists, on the other hand, of comparatively soft red marls low-lying ground has resulted, in particular the famous fertile plain of central Hereford which is thus a basin-shaped plain lying within the bounds of the Welsh massif. An attempt has been made in Fig. 190 to divide the Welsh massif into its smaller constituent regions.

The Peninsula of Devon and Cornwall.—The south-western peninsula is the third of the masses of ancient rocks which occur on the western side of England and Wales. It is very different in character from the Lake District massif, and also from the Welsh massif. The folding of the rocks is very complicated and took place, for the most part, during the Carbo-Permian or Armorican earth movements, and the strike of the folds is east to west. During the folding there was an intrusion of large granite masses. Thus from early Permian times onwards, as already pointed out, there must have been great east and west mountain chains separated by deep rock-girt basins in which the Permian and Triassic rocks were laid down. But through the long ages since, denudation has been active, and the ancient mountain chains have been worn down until now there are certainly no rugged mountains in Devon or Cornwall. Instead there is an elevated plateau rising to its greatest heights either where the old rocks are very hard or tough, as in Exmoor, or where the granite masses have offered a greater resistance to denudation than the surrounding sediments, as they have in Dartmoor and Bodmin Moor and other areas. The south-western peninsula also seems to have undergone a comparatively recent general uplift, so that at the present day we may best describe the area as a plateau with an undulating surface—a plateau which

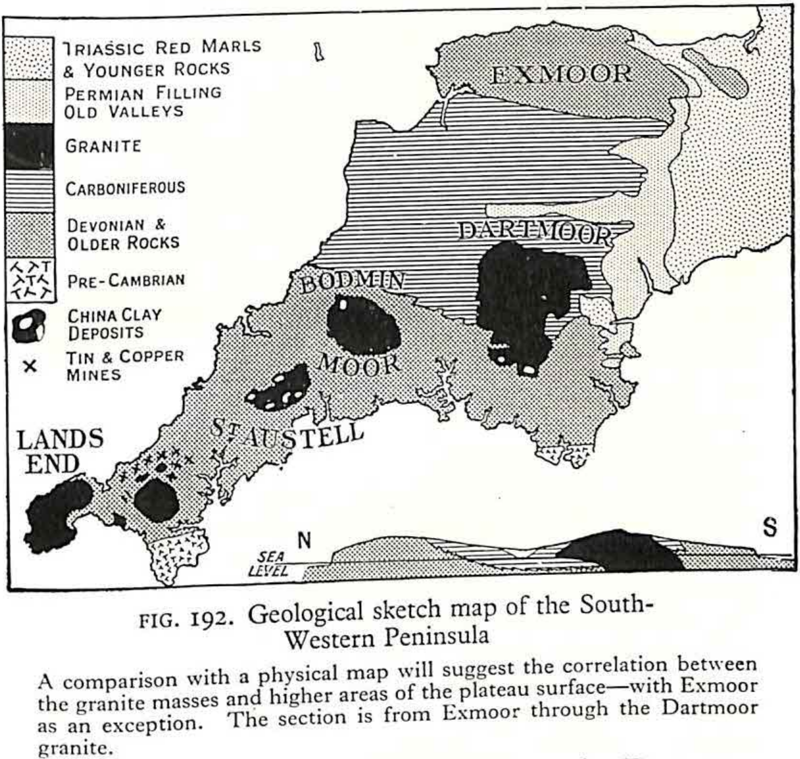


FIG. 192. Geological sketch map of the South-Western Peninsula

A comparison with a physical map will suggest the correlation between the granite masses and higher areas of the plateau surface—with Exmoor as an exception. The section is from Exmoor through the Dartmoor granite.

meets the present ocean in the long succession of rugged cliffs, so characteristic of the coasts of Devon and Cornwall. A part of western Somerset (the Quantocks) is also included within this region. The higher levels of the plateau are occupied by moorlands, but much of the remainder is cultivated, since the Devonian and Carboniferous rocks break down into a moderately rich soil.

The Pennines.—The Pennines, or the "Backbone" of England, are sometimes wrongly referred to as a chain of mountains. This term is entirely incorrect, and it is much more suitable that they should be referred to as the Pennine Upland. It is probable that Coal Measures were deposited, as we have already seen, right across the north of England, and that the Pennine Uplift dates from post-Carboniferous times, that is from the Carbo-Permian earth movements. The Pennines are often represented in diagrammatic sections as if they were a simple anticline. Broadly speaking, however, the fold, if such it may be called, is defined by a series of great faults on the west, and consequently the highest portion of the Pennines is usually the western margin overlooking the lowlands to the other side of the boundary faults. The Carboniferous Limestone and Millstone Grit rocks which make up the

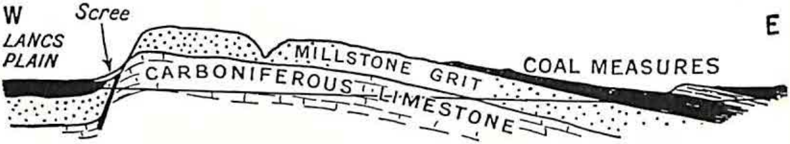


FIG. 193. Section across the Middle Pennines, between the Lancashire and Yorkshire coalfields. Notice the boundary fault on the west, which is clearly a fractured monocline.

bulk of the moor-covered Pennine Uplands are themselves but slightly folded, often almost horizontal, but towards the east they take on a general dip towards the North Sea, so that on the eastern side the Pennines fade gradually into the lower ground bordering the North Sea itself. Important transverse valleys divide the Pennines into a number of blocks.

The Triassic Plain of the Midlands.—Turning now to the lowland regions, the Midlands of England occupy a V-shaped area. The southern end of the Pennines fits into the centre of the " V," the left arm of which joins the lowlands of Cheshire and Lancashire, through the Midland Gap, while the right arm joins the lowlands of the Vale of York by way of the broad lower Trent Valley. Geographically the Midlands so defined may be regarded as bounded on the south-east by the first of the " scarps " which make up the scarplands of south-eastern England. On the west the Midlands stretch as far as the edge of the Welsh massif, which has already been described. The point of the " V " stretches to the Severn estuary. The most important of the geological formations in the Midlands is the Upper Trias or Keuper Marls, which weather to a rich red soil excellent for cattle pastures and for cultivation. The Lower Trias or Bunter is a formation of sandstones which results in rather higher and less fertile country, such as the Cannock Chase plateau. The whole of the Trias was originally laid down in a shallow inland basin under almost desert conditions (compare the Great Salt Lake of Utah at the present day), and the Triassic deposits are found wrapping round masses of older rock which formed islands in the old lake basin. The "islands" include the small coalfields of the Midlands together with the "islands" of still older rocks.

The chief islands of old rocks are as follows:

(*a*) *Charnwood Forest.* This consists of very ancient (Pre-Cambrian) rocks, though all but the highest hills of the ancient island have been covered with Triassic deposits. Some of the old rocks are quarried for road metal, which is used all over southern England.

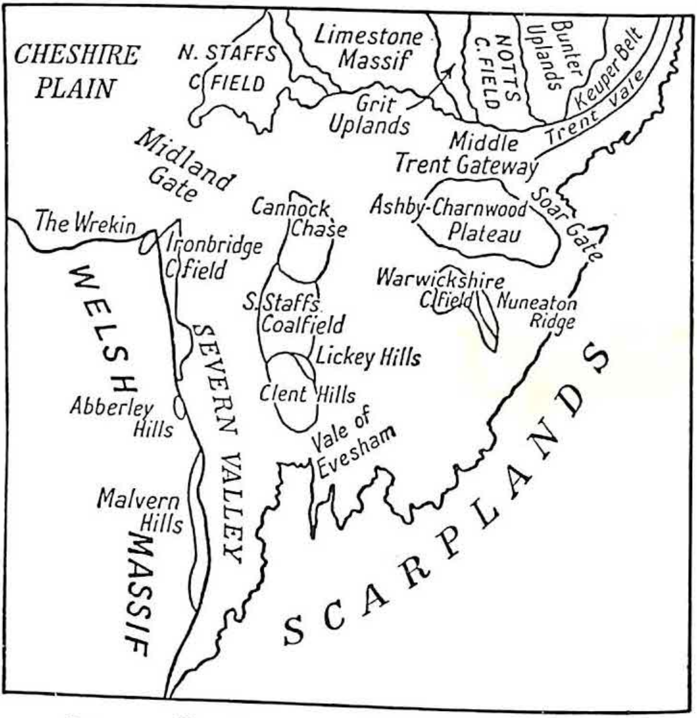


FIG. 194. Sketch map showing physiographic subdivisions of the Midlands

(*b*) *The Leicestershire Coalfield.* This lies next to Charnwood Forest on the west. The coalfield and Charnwood Forest form an upland area which has been called the Ashby-Charnwood Plateau.

(*c*) *The Nuneaton Ridge.* This is a narrow ridge of ancient rocks similar to those of Charnwood Forest.

(*d*) *The Warwickshire Coalfield.* Also called the Nuneaton Coalfield, it lies to the west of the Nuneaton Ridge, just as the Leicestershire field lies to the west of Charnwood Forest.

(*e*) *The Lickey Hills.* South of Birmingham is a very small island of ancient rocks like those of the Nuneaton Ridge—these are the Lickey Hills.

(*f*) *South Staffordshire Coalfield.*—This large and important coalfield lies immediatly to the north-west. The northern part is a broad plateau, continued northwards by Bunter Sandstones and known as " Cannock Chase," whilst a continuation southwards of the Bunter Sandstone gives rise to the Clent Hills. Associated with this coalfield is the famous " Black Country."

(*g*) *The Ironbridge and Forest of Wyre Coalfield* (East Shropshire Coalfield). This is a long, narrow coalfield stretching southwards from Wellington and lying along the edge of the Welsh massif. It is cut through by the gorge of the Severn.

(*h*) *The Wrekin.*—This is a hill of ancient rocks near Wellington, which forms the corner of the Welsh massif.

The Keuper Marls of the Midlands give rise to low ground, gently undulating but otherwise rather featureless.

To the south-east the Keuper Marls are succeeded by the Rhætic and Liassic rocks. Unless these contain hard or resistant beds sufficiently important to give rise to a scarp there is little to mark the junction. Thus the Vale of Evesham is partly on Keuper, partly on Lias; so also is the Vale of Berkeley.

The Plain of Lancastria.—The plain of Lancastria forms a continuation of the Midland Plain through the Midland Gap or Midland Gate. It occupies the northern half of Shropshire, nearly the whole of Cheshire and that part of Lancashire which lies between the Pennines and the Irish Sea. There are two broad tongues of moorland, called respectively Bowland " Forest " and Rossendale " Forest," which extend westwards from the Pennines into Lancashire and which coincide with anticlines of Carboniferous Rocks (Millstone Grit and Lower Coal Measures). Elsewhere Lancashire is an undulating lowland: again, where Bunter Sandstones outcrop there may be low hills, where the Keuper Marls are at the surface true lowland prevails. The actual character of the surface, however, depends largely on the thickness and type of the mantle of glacial deposits.

The North-Eastern Lowlands.—On the eastern side of the Pennines, and thus corresponding to the Plain of Lancastria on the west, is a broad belt, mainly of lowland. The Carboniferous Limestone and Millstone Grit formations which make up the bulk of the Pennines dip eastwards, and are succeeded in turn by the Lower Coal Measures, the Middle and Upper Coal Measures, the Magnesian Limestone and higher Permian beds, the Bunter Sandstone and the Keuper Marls. This is found both in the Yorkshire and in the Northumberland and Durham Coalfields. In general terms each succeeding formation gives rise to its own characteristic type of country. Thus there is a succession of physiographic zones roughly parallel to the Pennines. The Lower Coal Measures give rise to rather barren land with patches of moorland separated from one another by river valleys. The more fertile country of the Middle and Upper Coal Measures has a gentler relief, but resistant beds may form westward facing scarps (cf. Fig. 130). Tongues of lowland extend into the heart of the Pennines along the famous "Yorkshire Dales"—particularly those formed, from north to south, by the Swale, Ure, Nidd, Wharfe, Aire, Calder, and Don. The Magnesian Limestone usually forms a distinct westward facing scarp, often with attractive cliff scenery, especially at those parts where the scarp is cut through by rivers. The Bunter Sandstone, as in the Midlands, coincides with sandy, rather elevated tracts, infertile and hence often well wooded as in the well-known Sherwood Forest. Occasionally marked bluffs are found, such as that on which Nottingham Castle is situated. The final belt is that of the Keuper Marls and is the lowland belt which stretches from the mouth of the Tees to the Trent Vale of Nottinghamshire, but the Keuper Marls are masked by superficial deposits over large areas, particularly over that huge tract known as the Vale of York.

The Bristol-Mendip Region.—To the south-west the Midland Plain narrows and passes first into the Vale of Gloucester and then into the Vale of Berkeley between the Forest of Dean or the Severn on the west, and the fine scarp of the Cotswolds on the east. But further southwards, in what may be called the Bristol-Mendip Region, the plain disappears. This region repeats, on a smaller scale, the features of parts of the Midlands. It really consists of " islands " of old rocks wrapped round by the softer Triassic and Liassic deposits. But there are several points of difference: the islands are relatively larger and more numerous, the amount of low ground correspondingly small. The islands, too, are of rocks of varied age; there are the large Carboniferous Limestone masses of the Mendip Hills, and the important coal basins, as well as quite tiny patches of Silurian, Old Red Sandstone and Carboniferous Limestone. The " islands " are remnants of Armorican folds, and it is in this region that the north-south Malvernian folds cross the more normal east-west folds which have, however, in the Mendip Hills assumed a direction rather west-north-west to east-south-east. Thus some of the old blocks are elongated in a north-south direction, others in the direction exemplified by the Mendip Hills.

The Plain of Somerset.—In some ways this plain resembles that of the Midlands from which it is separated by the Bristol-Mendip region. The Vale of Taunton Deane is thus a Keuper Marl lowland, but the great feature of Somerset is the very extensive plain, almost at sea-level and liable to extensive floods, which lies between the Quantock Hills and the Mendip Hills, and which is interrupted only by the narrow Liassic ridge of the Polden Hills.

The Jurassic Scarplands.—The Jurassic rocks of Britain crop out over a belt of varying width extending from the Dorset coast to the north Yorkshire coast. Over large areas the beds dip to the south-east or east, and so give rise to a succession of hills or ridges where the harder or more resistant beds crop out, and valleys or negative relief where the softer or more easily eroded rocks occur. The hills usually have a steep scarp slope on the one side, generally to the north-west, and a long gentle dip slope on the other. Whilst the general arrangement

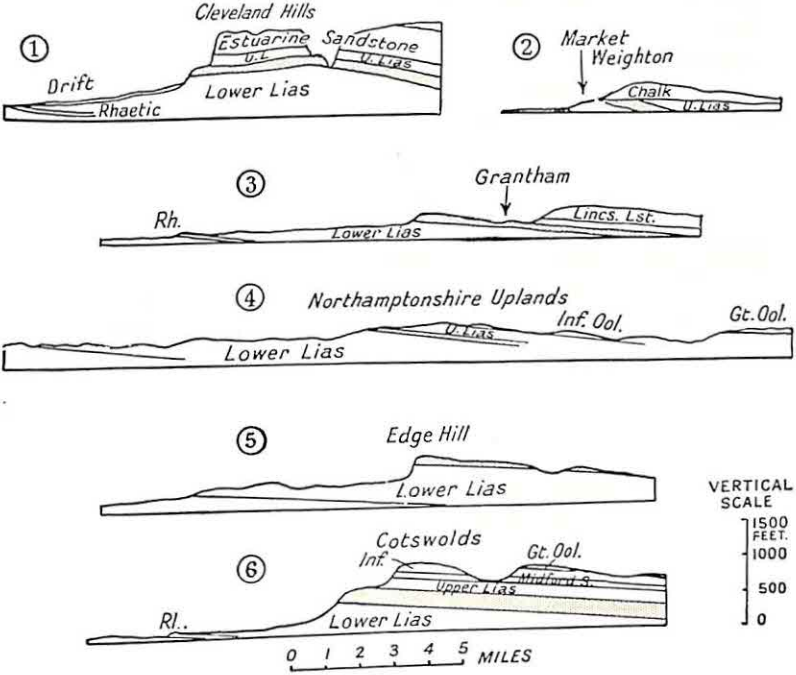


FIG. 195. Some typical sections across the scarplands

Stippled band = Middle Lias (mainly sandstone and marlstone).

is that suggested in Fig. 130, it is a mistake to imagine a continuous Jurassic limestone scarp running right across the country. The hill-belts and scarps are not formed by a single rock formation, but by different rock groups in different areas. The scarps swing about in different directions, die away, and start again. In some parts of the Midlands, the dip slope of the resistant beds is so slight that the structure of the country becomes that of a dissected plateau. Thus the Jurassic scarps are not nearly as constant as that of the Chalk.

In the first place the Jurassic rocks were laid down in shallow water, and consist of a varied series of clays, fine and coarse sands, sandstones and limestones. Some of the latter are oolitic, but the importance of the oolitic limestones has been over-emphasised as a result of their economic value as building stones or for lime. The variability of the Jurassic succession was enhanced by the presence within the sea of three axes of uplift which, by separating the sea into four different basins, allowed a different succession of clays, sands, and limestones to accumulate in each basin. Along the axes, which lay respectively east-west across South Yorkshire, north-west to south-east across Oxfordshire and west-north-west to east-south-east along the line of the Mendip Hills in Somerset, the whole Jurassic sequence is naturally thin.

The main Clay Vale is formed generally by the clays of the Upper Jurassic. In Yorkshire it is represented by the old glacial lake basin of the Vale of Pickering (on Kimmeridge Clay). The Lincoln Vale broadens out southwards to the great flat of the Fens where the solid geology is completely masked. Fenland is thus an extension of the great Clay Vale.

The Chalklands.—That pure white limestone known as chalk, although soft, is more resistant to weathering than the clays or sands which underlie it and the more recent sediments by which it is sometimes succeeded. As a formation it is thick—600 to 1,000 feet generally—and varies but little from Yorkshire to the Isle of Wight. Consequently it gives rise to a scarp, in general westward facing, which is both more conspicuous and more continuous than the scarps formed by the Jurassic rocks. Only rarely—as in the East Anglian Heights—is this feature inconspicuous, even more rarely is it absent. The dip slope of the chalk is characteristically "rolling" country and innumerable dry valleys are a constant feature. Where the chalk is almost horizontal large stretches of rolling downland (typified by Salisbury Plain) result; where the dip of the beds is steep there is little difference between the dip slope and the scarp slope and "hog's back" lines of hills result, like the Hog's Back between Guildford and Farnham. The belt of chalkland commences in the north in Yorkshire (where it forms the Yorkshire Wolds). It is interrupted by the Humber and forms the ridge through which that river passes just before reaching Hull. Southwards are the Lincolnshire Wolds, as far as the second interruption caused by the Wash. In both the Yorkshire and Lincolnshire Wolds the character of the chalklands is modified by a thick mantle of glacial

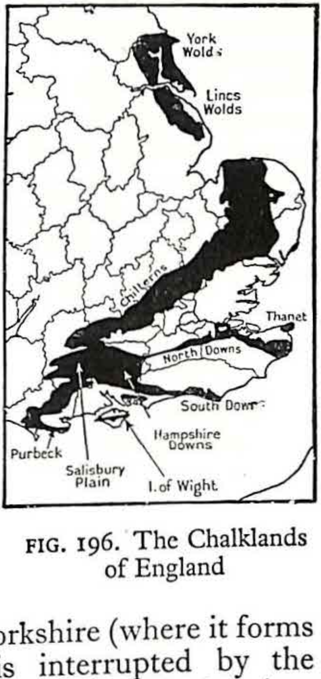


FIG. 196. The Chalklands of England

deposits. From the chalk cliffs of Hunstanton in Norfolk, the scarp is represented merely by low hills overlooking the Fens. In the neighbourhood of Newmarket, the chalk hills become more distinct (East Anglian Heights) and gradually the great stepped scarp of the Chiltern Hills becomes increasingly marked. The River Thames cuts through the chalk ridge by the Goring Gap. In Berkshire and northern Wiltshire the chalk outcrop broadens to form the Lambourn and Marlborough Downs. In this part of England certain beds below the chalk, especially the Upper Greensand (here a close-grained loamy clay), assume a special significance. The important Vale of Pewsey is floored by the Upper Greensand. To the south is the great stretch of Salisbury Plain. The chalk downs extend into Dorset. From here westwards an important feature is formed by the Greensand deposits—here with more resistant beds—which give rise to the Blackdown Hills.

Along the south coast tracts, Britain was considerably affected by the Alpine earth movements, and the highly folded chalk—almost vertical in places—gives rise to a ridge through the Isle of Purbeck and then the Isle of Wight.

To the north and south of the Weald are the North Downs and South Downs respectively (see below).

The Weald.—Originally the whole of south-eastern England was covered with a thick mantle of chalk, and the uplift of the Wealden dome took place during the Alpine earth movements. The crest of the dome, which is elongated from east to west, trends on the whole in that same direction, but the axis curves towards the south-east when followed over the Straits of Dover into the northern part of France. The development of the Wealden rivers has already been discussed. The rocks underlying the chalk in the Weald belong to the Lower Cretaceous Series, and there are alternating soft, or easily eroded, beds, mainly clays, and harder, or more resistant beds, mainly sands and sandstones. One thus has a repetition in miniature in the Weald of the features of the scarplands of England, with each successive ridge showing a scarp facing towards the centre, as suggested in Fig. 197. At a late stage in the history of the area, the Straits of Dover were cut and occupied by the sea across the eastern end, so that the extreme east of the Weald is actually in France. In the heart of the Weald as it is to-day is a group of sandy beds forming hills once covered with thick forest, and so often known as the Forest Ridges. Surrounding these hilly central tracts is a belt of lowland where the Weald Clay and certain other clayey beds are found, then a belt of hills formed by the harder beds of the Lower Greensand, then again a valley, called in the north the Vale of Holmesdale, which marks in the main the position of the soft Gault clay. Then comes the main ridge of all, formed by the chalk, well known as the North Downs in the north and the South Downs in the

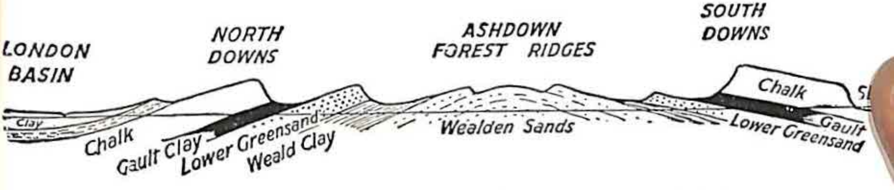


FIG. 197. Diagrammatic section across the Weald from north to south

south. The Downs present a steep scarp slope inwards towards the heart of the Weald, and then a long gentle dip slope in the reverse direction. Sometimes the dip of the chalk is steep, as in the famous Hog's Back west of Guildford, and the apparently simple structure shown in the diagram may be complicated locally, especially where the escarpments are " stepped " and certain horizons, *e.g.* the Lower Chalk, give rise to platforms. Although the Weald is thus a well-marked region, it will be seen that it comprises a number of different parts, shown in Fig. 198.

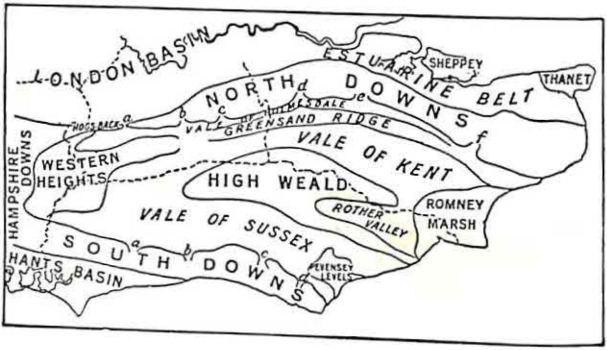


FIG. 198. The minor regions of the Weald

Strictly speaking the Weald may be regarded as limited by the main crest of the chalk scarp, but it is often convenient to consider as belonging to it the chalk downs as well. The chalk ridge maintains an average elevation of 500 to 700 feet, and there is a drop of 400 feet or more to the Gault Clay Vale. The importance of the gaps through the ridge is at once apparent. Along the North Downs the chief gaps and gap towns from west to east are (the letters refer to Fig. 198):

(*a*) The Wey Gap—Guildford.
(*b*) The Mole Gap—Leatherhead and Dorking.
(*c*) The Merstham Dry Gap—Redhill and Reigate.
(*d*) The Darent Gap—Otford and Farningham.
(*e*) The Medway Gap—Rochester.
(*f*) The Stour Gap—Canterbury.

Along the South Downs are:

(*a*) The Arun Gap—Arundel.
(*b*) The Adur Gap—Steyning.
(*c*) The Ouse Gap—Lewes.
(*d*) The Cuckmere Gap.

The London Basin.—The London Basin is both a geographical and a geological unit. Geologically, it is a broad synclinal basin with a clearly defined chalk rim and a central portion occupied by sands and clays of the Tertiary sequence, by gravels of varied origin, and by alluvium. The London Basin, a syncline as a whole, is not symmetrical. Its axis is towards the southern edge, and it is to be noted that it is along this line that the lower River Thames flows. Then there is quite an important fold in the centre with an east-west trend, sometimes known as the Thames Basin or the London Basin Anticline. These minor structures, combined with the very varied character of the young sedimentary rocks which fill in the basin, are responsible for its very varied morphological character. It can, therefore, be divided into many minor regions.

The Hampshire Basin.—In many ways the Hampshire Basin resembles the London Basin. There is a surrounding girdle of chalk downs and a central region of later clays and sands. Instead, however, of the basin being open to the sea to the east, its southern chalk rim has been cut through by the sea in two places—at each end of the Isle of Wight. Although strictly speaking the Hampshire Basin might be limited to the central area of Tertiary rocks, it is convenient to consider the surrounding area of chalk downs also in any general geographical consideration of the Basin. There is thus the Tertiary belt of the heart of the basin, and the surrounding chalk lands. As in the case of the London Basin, subsidiary folds occur, and one important one brings up the chalk to form the Portsdown Hills to the north of Portsmouth (see Fig. 199). The Tertiary belt differs from that of the London Basin in the rather larger proportion of coarse or mixed sands. These are especially important in the south-west, where the New Forest is found on sandy areas of this character. The more varied of the Tertiary rocks give rise to sandy and loamy soils suitable for mixed farming, and have a low but varied topography. The southern rim of the Hampshire Basin

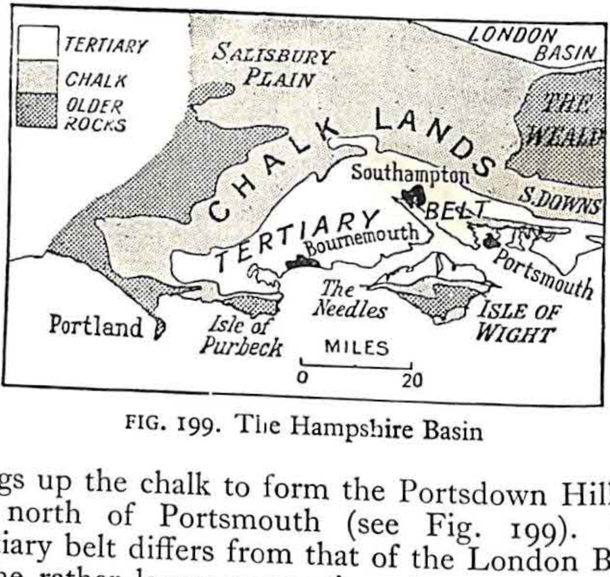


FIG. 199. The Hampshire Basin

is formed by a sharp fold of chalk which cuts across the Isle of Wight, following its longer axis. To the south of this central ridge in the Isle of Wight there are early Cretaceous rocks, giving rise to varied country, repeating on a small scale some of the features of the Weald. In the so-called Isle of Purbeck still older rocks appear, and one sees part of the Jurassic sequence of the Jurassic scarplands.

East Anglia.—East Anglia corresponds roughly with the counties of Norfolk and Suffolk. Chalk underlies most of the western two-thirds of this tract and later Tertiary rocks the eastern third, but the whole tends to be so thickly covered with glacial and other deposits that East Anglia is very far from resembling the well-known chalk downland. At the present day it is difficult to realise the former isolation of East Anglia. It is bounded on the north and east by the sea. To the south it stretched as far as the once thickly forested damp lowlands of Essex ; on the west lay the impassable marshes of the Fenlands, and it was only to the south-west that East Anglia could be approached along the comparatively dry route afforded by the chalk country of the East Anglian Heights. Though the former isolation has disappeared, East Anglia remains a remarkable geographical entity. The character of East Anglia varies mainly according to the nature of its surface deposits. The whole is a low plateau with an undulating surface, often indeed almost flat, and in which those towns and villages situated along the river courses tend to be hidden, as, for example, in the case of Norwich. A special feature of interest is that area known as the Broads—wide stretches of shallow water, where the rivers have been ponded back by the formation of bars preventing the free flow of their waters to the North Sea.

Ireland.—Physiographic units of Ireland connect very closely with those of England and Scotland. In the north-west there are masses of ancient metamorphic rocks which form a continuation of the Highlands of Scotland. In the north-east there is the natural continuation of the Southern Uplands of Scotland. Between the two there should be a western extension of the Midland Valley of Scotland, but this actually is obscured by the huge spread of lava which makes up the so-called Antrim Plateau, a saucer-shaped basalt plateau with the large but shallow Lough Neagh in the centre. The Mourne Mountains are formed by a mass of granite intruded into rocks which are a continuation of the Southern Uplands of Scotland. The south-east of Ireland is occupied by the Wexford Uplands and the Wicklow Mountains. Doubtless the Wexford Upland area was formerly continuous with the main mass of Wales with which it is geologically and structurally allied, whereas the Wicklow Mountains represent an enormous mass of granite, the largest in the British Isles. South-western Ireland is characterised by a succession of sandstone ridges and limestone valleys. The sandstone is mainly of Old Red Sandstone age, the limestone is the Carboniferous Limestone. The folding is Armorican ; the folds are not quite east and west, the general trend being from west-south-west to east-north-east. The heart of Ireland is occupied by a great plain—the Central Plain—represented on geological maps as consisting of an enormous mass of Carboniferous Limestone. Through this there appear isolated mountain masses consisting either of older rocks, which appear in the form of anticlinal masses from beneath the limestone, or which represent the remnants of younger rocks of Coal Measure age. Actually the Carboniferous Limestone in the heart of Ireland is very rarely seen. It has been covered to a great depth, either by a mask of bog and peat or by sands, clays, and other deposits which were left behind during the retreat of the great ice sheets.

INDEX

Abberley hills, 227
Absorption, 66
Accidented topography, 132
" Acid " rocks, 104
Aclimatic soils, 162
Adelaide, 176
Æolian deposits, 49, 61, 96
Alpine climate, 186
Africa, 20, 22, 45, 46
Agglomerate, 106
Ajanta Range, 156–7
Alaska, 33
Aletsch Glacier, 31
Algæ, 103
Alluvial fan, 52
Alluvial gold, 43
Alluvium, 51
Almond, 177
Alpine-Himalayan system, 91
Alpine movements, 195, 208
Alpine pastures, 186
Alpine structure, 92
Alps, 31, 125, 186, 211
Altaid movements, 203
Altaid Mts., 203
Amazon, 166, 168, 169
Ammonites, 206
Andes, 14, 25, 94, 211
Andesite, 105
Anglesey, 227
Animals, action of, 37, 60
Animal life, 165 *et seq.*
Ankor, 39
Antarctic, 31, 183, 186
Antecedent drainage, 159
Antelopes, 170
Anthracite, 101
Anticline, 83, 84
Anticlinorium, 86
Anti-cyclone, 124
Anti-Trades, 121
Antrim, 212
Antrim lavas, 68
Antrim Plateau, 248
Apennines, 80
Apricots, 177
Aqueous rocks, 62
Arabia, 173, 182
Arabs, 182
Arakan Yoma, 210
Arctic, 31
Arctic climate, 183
Arenaceous rocks, 97
Arête, 138
Arequipa, 47
Argand, 91
Argentina, 25
Argillaceous rocks, 99
Arizona, 70, 144, 145
Arkose, 98
Armorica, 203
Armorican movements, 195, 203
Armorican trend, 204
Artesian wells, 164
Ash cone, 68, 71
Ashes, 106
Asia, 123
Assam Basin, 210
Assimilation, 116
Asymmetrical folds, 83
Atacama, 173
Atacama Desert, 102
Atlantic coasts, 149, 150
Atlas, 211
Atmosphere, 7, 116 *et seq.*
Atmospheric weathering, 13
Augite, 105, 111
Aureole, 66
Australia, 171
Australia, rain, 129
Avalanche, 29

Badlands, 142, 143
Baltic Sea, salinity, 187
Baluchistan, 80
Bamboo, 172
Bananas, 172
Banded sediments, 53–54
Banff, 181
Barbados, 94
Barley, 179
Barometer, 117
Barren lands, 186
Bars, 57
Barysphere, 5–6, 65
Basalt, 7, 103, 105, 108, 109, 114
Base level, 155
" Basic " rocks, 105
Basin, 85
Basin, artesian, 164
Basin cultivation, 22
Bath freestone, 206
Batholith, 66
Bays, 36
Beach deposits, 97, 98
Bedding planes, 83
Bedford Level, 7
Beech, 179
Belemnites, 206
Belgium, 85
Bengal, 203
Ben Nevis, 220
Berkeley Vale, 235
Biological weathering, 160
Biotite, 111
Birch, 179
Blackdown Hills, 242
Black earth, 162
Blackheath, 140
Black Sea, salinity, 187
Block mountains, 90
Bodmin Moor, 230
Bombs, 68, 106
Bone-beds, 101, 206
Boulder clay, 34, 55, 99
Borax, 102
Bore, 192
Boss, 66
Bournes, 147
Bowland Forest, 236
Brackish water deposits, 97
Brahmaputra, 159
Brazil, 178
Brazilian Plateau, 20
Breadfruit, 172
Breccia, 96, 97
Brecon Beacons, 230
Brickearth, 46
Bristol-Mendip, 237
Brittany, 203
Broads, 158
Bromo, Mt., 71
Brown coal, 101
Brown forest soils, 162
Bruchen, 88
Buckling, 87
Bude, 86, 87
Building stones, 114
Bunter, 205
Burma, 28, 53, 63, 73, 80, 106, 142, 143, 168, 171
Burma coasts, 151
Burma granites, 208
Burmese Basin, 210, 211
Bush veld, 170
Buxton, 148

Cacao, 168
Cader Idris, 199, 228
Cainozoic (Kainozoic), 194
Calabar, 21
Calcareous sandstone, 98
Calcareous tufa, 102
Calcite, 110, 111
Caledonia, 200
Caledonian movements, 195, 199
Caledonian trend, 200
California, 40–41, 79
Cambrian, 197
Camel, 175
Canada, 181
Canada, western, 178
Canadian shield, 93, 135, 137
Cannock Chase, 233, 235
Cape St. Vincent, 176
Carbon, 101
Carbonaceous rocks, 101
Carbon dioxide, 23
Carbonic acid, 23
Carboniferous limestone, 95, 199, 202
Carboniferous times, 201
Carbo-Permian, 203
Carpathians, 125, 131, 183, 211
Caspian Sea, 204
Cassiterite, 113
Cattle, 179
Caucasus, 211
Caverns, 24, 102
Caves, 36, 38
Cell sap, 38
Cement, 114
Cementation, 103
Central Lowlands of Scotland, 223
Centrifugal force, 190
Ceylon, 166
Chalk, 11, 22, 26, 60, 100, 208
Chalklands, 240
Chalk, peneplanation, 208
Chalk Sea, extent, 209
Charnian movements, 195
Charnwood, 234
Chemically formed rocks 96, 101 *et seq.*

Chernozem, 162
Chert, 98, 101
Chile, 46, 47, 102, 178
China, 177, 178
China clay, 114, 115
China clay works, 61
China, Northern, 49, 51
Chindwin River, 142
Chinook, 125
Chlorophyll, 116
Cinchona, 168
Cirque, 138, 140
Classification of rocks, 96
Clay, 11, 22, 99
Clay vales, 141, 207
Clay-with-Flints, 103
Clent Hills, 235
Cliffs, 35, 36, 37
Climate, 129
Climatic divide, 130
Climatic Regions, 165 *et seq.*
Clints, 148
Coal, 101
Coal measure plants, 202
Coal measure times, 200, 203
Coal mine, 112
Coasts, 35, 36
Cocoa, 168
Coconuts, 168
Coffee, 172
Cold deserts, 183
Cold temperate climate, 182
Colorado Canyon, 144–5
Colorado Desert, 174
Compensation, 10
Compression, 83, 94
Conglomerate, 97
Congo, 166, 168, 169
Coniferous forests, 181, 182
Consequent rivers, 151
Continental climate, 180
Continental deposits, 97
Continental drift, 10
Continental platform, 36–38
Continental shelf, 8, 11, 60, 187
Continental slope, 11, 60
Convectional rains, 127
Cool temperate, oceanic climate, 178
Copper, 113
Copper pyrites, 113
Coprolites, 101
Coral, 100
Coral islands, 95
Coral rag, 100
Coral reefs, 100
Coral rocks, 100
Coralline crag, 100
Cornwall, 61, 69, 86, 87, 107, 190, 230
Cornish granite, 195
Corrasion, 13
Corrie, 138, 140
Cotton, 172, 178
Crag, 100
Crag and tail, 31, 34
Crags, 24, 25
Crater, 72
Crater lake, 75
Cretaceous times, 207
Crevasse, 30, 32
Cromer Ridge, 55
Crystal form, 110
Crystalline rocks, 108
Cubic, 110
Cuestas, 141
Cumbria, 224
Current-bedding, 52
Currents, 189, 191
Currents, effect of, 189
Cwm, 140
Cycle of erosion, 132 *et seq.*
Cyclones, 17, 124, 126
Cyclonic rain, 127
Czechoslovakia, 137

Dakota, 48
Dales, Yorkshire, 237
Dalmatia, 148
Darjeeling, 184–5
Dark Mica, 105, 111
Dartmoor, 109, 230
Date-palm, 174
Deccan, 179
Deccan lavas, 68, 156–7, 208
Deciduous trees, 26
Dehra Dun, 133
De Martonne, 135
Delta, 52
Dendritic drainage, 151, 152
Denudation, 13 *et seq.*
Denudation, definition, 13
Deposition, 44 *et seq.*
Depressions, 124
Derbyshire, 148
Deserts, 17, 45
Desert climates, 172
Desiccation, 216
Devon and Cornwall, 230
Devonian, 199, 200, 201
Devonshire, 109
Diameter of earth, 1
Diatoms, 100
Diatom ooze, 60
Didymograptus, 196
Diorite, 105
Dip, 83
Dip faults, 89
Dip slope, 141
Dip valleys, 152
Diplograptus, 196
Dolerite, 103, 105, 114
Dolina, 149
Dolomite, 100
Dormant volcanoes, 69
Dorset, 211
Downland, 181
Downthrow, 88
Drainage systems, 42
Dreikanter, 17
Drumlins, 56, 57, 139
Dry valleys, 147
Dune sand, 96
Dust, 44, 46
Dust storms, 44 *et seq.*
Dyke, 66, 67, 103
Earth, age of, 194
Earth, curvature, 2
Earth, deformation, 10
Earth, density, 5
Earth, diameter, 1
Earth, history, 194 *et seq.*
Earth, movements, 4
Earth, origin, 8
Earth pillars, 20
Earth, shape, 1
Earth, size, 2–3
Earth, structure, 5
Earth, weight, 5
Earthquakes, 6, 77 *et seq.*
Earthquake belts, 78–80
Earthquakes, effects of, 80
Earthquakes, intensity, 78
Earthworms, 39
East Anglia, 212, 247
East Anglian Heights, 241
Eastbourne, 58
East Indies, 166, 168, 169
Ebb tide, 192
Eclipse, 10
Egypt, rivers, 134
Egyptian desert, 173
Elbe, 56
Elm, 179
Entrenched meanders, 158
Eocene, 208, 209
Epeirogenetic, 83
Epicontinental seas, 11
Epicentre, 77
Equatorial climate, 165
Eras, 194
Erosion, 13
Erosion cycles, 132 *et seq.*
Erratics, 55
Esker, 56
Essex, 62
Essex, rain, 128
Estuarine deposits, 61, 97
Eucalypts, 174
Eustatic movements, 94
Evesham, 235
Evolution, 64
Exmoor, 230
Expansion, 13
Extinct animals, 64

Fall, The, 179
False-bedding, 52
Fan-shaped structures, 86
Faulting, 87
Faults, 77
Faults, age of, 93
Fault-breccia, 88
Fault scarps, 142
Felsite, 105
Felspar, 11, 12, 110, 111
Felspathic sandstone, 98
Fenland, 240
Fenland soils, 163
Ferruginous sandstone, 1
Finland, 33, 135
Fiords, 149, 150, 221
Firebricks, 115
Fireclay, 99, 115,
Firn, 29, 30
Fish, 193
Fish, fossil, 201
Fissure eruptions, 68
Flagstone, 99

Flexible sandstone, 99
Flint, 101, 111
Flood plain, 51
Floods, 63
Flood tide, 192
Florida, 190
Fluorite, 115
Fogs, 190
Fohn, 125
Folding, 77 *et seq.*, 83
Foliation, 107
Foraminifera, 100
Forest ridges, 243
Fossils, 61-64, 97, 194, 196 *et seq*
France, 47
Freestone, 114
French Indo China, 39
Fresh-water deposits, 61
Fresh-water limestone, 54
Frost, action of, 24-27
Fungi, 38
Gabbro, 105
Galena, 113
Galloway, 222
Ganister, 203
Garnet, 75
Gases, 69, 75
Gault, 208
Geoanticline, 86
Geoid, 1
Geology, definition, 1
Geomorphology, 132 *et seq.*
Geomorphology, definition, 1
Geography, definition, 1
Geosyncline, 87
Germany, 55, 56, 183, 204
Geyser, 74, 75
Glaceated country, land-forms, 135
Glacial deposits, 61, 97, 213
Glacial gravels, 97
Glacial interference, 139
Glacial period, 212
Glacial striæ, 30, 33
Glaciation, Britain, 138
Glaciers, 13, 30 *et seq.*, 54
Glei soils, 162
Glenmore, 220
Globigerina ooze, 59
Gneisses, 108
Gobi Desert, 174
Gold, 112
Gold, native, 112
Gondwanaland, 203
Goring Gap, 242
Gower, 136
Gräben, 90-142, 177
Graded bed, 155
Grand Canyon, 144-5
Granite, 11, 66, 104, 105, 108, 114
Granite cliffs, 190
Granite cores, 93
Granite, weathering, 15, 16, 109
Graphite, 101
Graptolites, 196
Gravel, 97
Great Ice Age, 55, 112, 213
Great Indian Desert, 173
Greece, 177
Greenheart, 168
Greenland, 31
Greensands, 208
Greenwich, 4
Greywacke, 98
Grikes, 148
Grits, 99
Groins, 57, 58
Ground moraine, 54
Ground water, 129
Guano, 101
Gulf, 36
Gulf stream, 190
Guinea coast, 166
Guinea oil palm, 168
Gypsum, 110, 115
Gypsum beds, 205

Hade of fault, 88
Hæmatite, 113
Hampshire Basin, 209, 245
Hanging valleys, 30, 140
Hango, 33
Harmattan, 46, 125
Harz Mts., 203
Hercynian movements, 203
Hereford, 230
Hexagonal, 110
Highland Boundary Fault, 80
Highlands, 92
Highlands of Scotland, 197, 198, 200, 219
High Tatra, 131
High Veld, 181
Hill-wash, 162
Himalayas, 91, 92, 124, 159, 210, 211, 212
Himalayan foothills, 133
Historical geology, 64, 194
History of Earth, 194 *et seq.*
Hog's Back, 241, 244
Homocline, 87
Hood, Mt., 70
Hornblende, 105, 111
Horst, 90
Horsts, 142
Horizons, soil, 160
Horizontal strata, 84
Hot-springs, 72, 75
Humboldt, 189
Hungry soils, 163
Hurricanes, 17, 190
Hurst Castle, 98
Hwang Ho, 51
Hyderabad, 16, 156-7
Hydrosphere, 7
Hypabyssal rocks, 103

Ice, action of, 29, 54
Icebergs, 54, 189, 190
Ice-cap, 31, 215
Ice-cave, 54
Ice-field, 31, 189
Ice-foot, 189
Ice-sheet, 31
Igneous rocks, 103 *et seq.*
Iguanodon, 207
Imbricate structure, 80
Immature soils, 162
Impervious rocks, 22, 164
India, 156-7, 171, 203
India, earthquakes, 82
India, structure, 81
Inselberg, 16, 146
Insolation, 14, 17
Interfluves, 134
Iran, 174
Ireland, 68, 202, 247
Iron, 111
Ironbridge, 235
Iron ores, 112
Iron oxides, 111, 113
Iron pyrites, 110, 113
Irrawaddy Delta, 63
Isoclinal strata, 86
Isohyets, 129
Isostasy, 10, 94
Isostatic movements, **95**
Istria, 148
Italy, 51, 78, 80
Ivy, 37

Japan current, 190
Java, 73, 75
Jointing, 93
Jupiter, 8
Jurassic reptiles, 207
Jurassic times, 205

Kainozoic, 194
Kalahari, 173
Kame, 56
Karst, 148, 149
Kent, 153
Kettle moraine, 56
Keuper, 205
Killas, 107
Kinchinjunga, 184-5
Knick points, 158

Labrador current, 190
Laccolite, 66, 67, 103
Lacustrine deposits, 97
Lagoon deposits, 97
Lake deposits, 56
Lake District, 128, 213, **224**
Lake, Oxbow, 51
Lambourn Downs, 242
Laminated rocks, 62
Lancastria, 236
Land and Sea Breezes, 122
Land-forms, 132
Land's End, 190
Landslips, 163
Laterite, 146, 161
Lateral moraines, 54
Latitude, 3
Laurentian climate, 179
Lava, 5, 67, 68
Lava cone, 70
Law of superposition, 53, **60**
Leaching, 161, 214
Lead, 113
Leeward side, 128
Lemons, 177
Lepidodendron, **202**
Levées, 51
Lianes, 166

Liassic, 206
Lickey Hills, 235
Life in ocean, 192
Lignite, 101
Lima, 79
Limbs, 83
Lime, 114
Limestone, 100, 108
Limestone country, 146
Limestone, weathering, 23
Limon, 47
Lithosphere, 5–7, 65
Loamy soils, 163
Local winds, 124
Loess, 46, 47, 49–50, 57, 96, 139
London, atmosphere, 23
London Basin, 209, 245
London Clay, colour, 24
Longitude, 3
Longitudinal valleys, 153
Lough Neagh, 248
Lulworth Cove, 211
Lunar eclipse, 10

Maelstrom, 192
Magma Basin, 65, 66
Magmatic absorption, 66
Magnesian limestone, 23, 112, 204
Magnesium carbonate, 100
Magnetite, 113
Mahogany, 168
Maize, 172, 178
Malaya, 166, 169
Malaya, granites, 208
Malaya, tin, 208
Malvern Hills, 204, 227, 228
Malvernian trend, 204, 228
Mammoth, 216
Mammoth springs, 72
Man, action of, 37, 60
Manchuria, 179
Mango, 172
Mangroves, 63
Mangrove swamps, 203
Manioc, 168
Maple, 179
Marbles, 108
Marl, 99
Marine denudation, 148
Marine deposits, 61, 97
Marine peneplanation, 148
Marine sediments, 58
Marlborough Downs, 242
Marlstone, 99, 206
Mars, 8
Master joints, 93
Matopo Hills, 15
Meander core, 158
Meanders, 51, 155
Mechanical action of rain, 20, 21
Mechanical analysis, soils, 163
Medial moraines, 54
Mediterranean, 129
Mediterranean climate, 175
Mediterranean Sea, salinity, 187
Melbourne, 176
Mendips, 237
Mercury, 8
Meridian, 4
Mesa, 141
Mesozoic, 194
Messina, 78, 80
Metallic vein, 67
Metamorphic aureole, 66
Metamorphic rocks, 96, 106 *et seq.*
Metamorphism, 66
Meteorites, 9
Meteoric hypothesis, 9
Mica, 11, 105, 111
Mica-schists, 107
Microgranite, 105
Midlands of England, 205, 233
Midland Valley of Scotland, 223
Mid-latitude grasslands, 180
Miller, C. J., 32
Millet, 178
Millstone Grit, 200, 203
Minbu, 114
Mineral oil, 101
Minerals, 11, 12, 110 *et seq.*, 96 *et seq.*
Mineralization, 68
Mineralizing waters, 68
Miocene times, 211
Mistral, 125
Molluscs, 193
Monadnocks, 134
Monkeys, 170
Monocline, 87, 89
Monoclinic, 110
Monograptus, 196
Monsoon climate, 171
Monsoon forest, 172
Monsoons, 123
Montenegro, 149
Moon, 9
Moraines, 31, 54
Mountain building, **77** ***et seq.***, 81, 82
Mountain knots, 92
Mountain limestone, 202
Mourne Mts., 195, 212, 248
Moving ice, action of, 54
Mt. Blanc, 117
Mud, 11
Mudstones, 99
Mud vein, 88
Mud volcanoes, 114
Muschelkalk, 205
Muskrat, 39

Napier, N.Z., 79
Natal, 177, 178
Neap tides, 192
Nebulæ, 9
Nebular hypothesis, 9
Neck, 68
Neptune, 8
Neuropteris, 202
Névé, 29, 30
New England, 179
New Forest, 246
New Guinea, 166
New Mexico, 152
Newquay, 69, 107
New Red Sandstone, 204
New York, sea temperature, 188
New Zealand, 179, 183
Norfolk Broads, 158
Normal faults, 89
North Downs, 244
Norway, 57
Norwich, 247
Nicaragua, 79
Nigeria, 21, 22, 43
Nitrate, 102
Nunataks, 135
Nuneaton, 235
Nuts, 177

Oak, 179
Oases, 174
Oats, 180
Oblate spheroid, 1
Obsequent streams, 153
Obsidian, 103, 105
Ocean currents, 37
Ocean, depth of, 11, 187
Ocean, life in, 192
Ocean, temperature, 188
Oder, 56
Ogygia, 196
Oil, 101, 115
Old Faithful, 74, 75
Old Red Sandstone, 201
Oligocene, 210, 211
Olive, 176
Olivine, 105, 111
Onion weathering, 15
Oolite, 102, 108, 114
Oolitic limestones, 206
Ooze, 59, 60, 100, 208
Oranges, 177
Ordovician, 197
Oregon, 70
Ores, 67
Organic rocks, 99 ***et seq.***, 96
Orkney, Is., 222
Orogenesis, sequence, 93
Orogenic period, 82
Orthorhombic, 110
Osmosis, 38
Outwash fans, 55
Overfold, 85, 88
Over-saturated, 105
Oxbow lake, 155
Oxygen, 116

Pacific, 100
Pacific coasts, 149, 150 151
Pack ice, 189
Palæozoic, 194, 197
Pampas, 180, 181
Pancake ice, 189
Papandajan, Mt., 73, 75
Parliament, Houses of, 23
Passive soil formers, 161
Paving stones, 99
Peaches, 177
Peat, 101
Pebbles, drift of, **57**
Pediment, 143

Pedology, 160
Pegu, 80
Peguan, 53
Pelagic deposits 59
Peneplain (peneplane), 134, 136
Peneplanation, 134
Peninsular India, 93
Pennines, 128, 204, 232
Pennine trend, 204
Permian sandstones, 204
Perched blocks, 54
Periodic Winds, 122
Periods, 194
Periods of mountain building, 92
Permanent water-table, 164
Permian marls, 204
Permian times, 204, 205
Persia, 174
Persian Gulf, temperature, 188
Perth, 176
Peru, 47
Pervious rocks, 164
Petrology, 108
Pewsey, Vale, 242
Phacolite, 66, 67
Phacops, 191
Pholas, 39
Physiography of British Isles, 217
Pickering, Vale of, 240
Pipe-clay, 54, 115
Pipes, 147
Pisolite, 103
Pitch of folds, 85, 86, 87
Planetary winds, 120
Planetismal hypothesis, 9
Planets, 8
Plankton, 93
Plants, action of, 37, 60
Plasticity, 99
Plateau of India, 93
Plateaus, 140
Pliocene times, 212
Ploughing, 26
Plutonic rocks, 104
Po, River, 51
Podsols, 162
Poland, 125, 131
Poles, 3
Pompeii, 71
Popa, Mt., 73, 106
Porous rocks, 22, 26
Porphyritic, 103
Porphyry, 104, 105
Portland stone, 207
Portsdown Hills, 246
Portugal, 176
Pothole, 28, 29
Prairies, 181
Pre-Cambrian, 194, 197
Pressure, atmospheric, 116
Primary, 194
Primary magma basin, 65
Profile, 160 *et seq.*
Pteropod ooze, 59
Puddingstone, 97
Pumice, 103, 105
Puna, 125
Purbeck, Isle of, 212, 242, 247
Pygmies, 169

Quantocks, 232
Quarries, 42
Quartz, 11, 12, 110, 111
Quartzite, 98
Quartzites, 107
Quartz-porphyry, 105
Quaternary, 194
Quetta, 80
Quinine, 168

Rabbits, 39
Race, 192
Radial drainage, 226
Radiation, 120
Radiolaria, 101
Radiolarian ooze, 60
Rag, 100
Raichur, 16
Rain, action of, 20, 21
Rain, chemical action, 22–24
Rainfall, 125 *et seq.*
Rainfall maps, 129
Rain gauge, 128
Rain shadows, 127
Raised beaches, 37, 95, 149
Range, annual, 119
Red clay, 60, 100
Red colours, 112
Red Sea, salinity, 187
Red Sea, temperature, 188
Red soils, 205
Reindeer, 183
Rejuvenation, 135, 158
Relief rain, 127
Reptiles, fossil, 207
Respiration, 116
Reversed faults, 88
Rhætic times, 206
Rhodes, C. J., 15
Rhodesia, 158, 170
Rhombs, 111
Rhone Glacier, 32
Ria, 149, 150
Rice, 172
Rifts, 142
Rift valley, 90
Rising coastline, 95
River capture, 153
Riverina, 180
Riverine deposits, 97
River terraces, 97
Rivers, action of, 50
Rivers, evolution, 150
Road metal, 113
Roches moutonnées, 30, 34
Rock-forming minerals, 110
Rock salt, 115
Rockies, 94, 211
Rocks, 5–6, 11, 96 *et seq.*
Rocks, change of colour, 24
Rocks, classification, 96
Rome, 177
Roothairs, 38
Rossendale Forest, 236
Rossi-Forel Scale, 78
Rubber, 168
Running water, action of 27, 50
Russia, 180
Rust, 111
Rye, 179

Sahara, 45, 173
St. Austell, 61
St. Lawrence type, 180
Sal, 7
Saline soils, 161
Salt, 102
Sand, 12, 18, 20, 44, 97
Sandbanks, 50, 52
Sand dunes, 45–47
Sandstone, 11, 22, 98, 108
Sand martins, 39
Satellites, 9
Saturn, 8
Savana, 169
Scarplands, 141, 207, 238
Scarp slope, 141
Scandinavia, 202, 215
Schists, 107, 108
Scotland, 128
Screes, 24, 25, 96, 97
Screes, angle of rest, 26
Sea, 187 *et seq.*
Sea, action of, 34, 57
Sea, currents, 34
Seasons, 4
Sea water, composition, 187
Sea water, gases, 188
Secondary, 194
Secondary magma basin, 66
Sedimentary rocks, 61, 96 *et seq.*
Seismograph, 6
Semi-deserts, 174
Serpentine, 105
Settle, 95
Shale, 11
Shales, 99
Shanghai, 18
Shape of earth 1
Shap Fell, 227
Sheep, 179
Sherwood Forest, 237
Shetland, Is., 222
Sial, 7, 90
Siam, 147
Siberia, 180
Silica, 12
Silicates, 12
Silicate zone, 7, 59
Sill, 66, 67, 103
Silts, 99
Siltstones, 99
Silurian, 197, 199, 200
Silver, 113
Sima, 7, 90
Simoon, 125
Sinking coastline, 95
Sirocco, 125
Skye, 221
Slates, 107
Slaty cleavage, 106, 108
Slickensides, 88
Slovenia, 26
Smith, William, 64

Snow, 29
Snowdon, 199, 228
Snow-line, 186
Soil, 24, 38, 160 *et seq.*
Soil Belts of World, 161 *et seq.*
Soil erosion, 20, 22, 40–43
Soil formation, 160
Soil profile, 160, 161 *et seq.*
Solar eclipse, 10
Solar system, 8
Solfataric stage, 69, 75
Solifluction, 162
Solonchak, 161
Solstice, 119
Solution hollows, 24
Somerset Plain, 238
Somma, Monte, 72
South Africa, 180
Southern Uplands, 200, 222
Spain, 140
Spheroidal weathering, 15
Sphinx, 19
Spits, 57
Sponge spicules, 101
Springs, 141, 163
Spring tides, 192
Stable blocks, 10, 212
Stable minerals, 110
Stack, 35, 36
Staffa, 109
Stalagmite, 102
Stalactite, 102
Stars, 9
Starfish, 193
State, 11
Steam action, 27 *et seq.*
Steppelands, 162
Steppes, 181
Stockwork, 67
Strata, 63
Stratigraphy, 64, 194
Striæ, 30
Strike, 83
Strike faults, 89
Strike valleys, 153
Structure of Britain, 210
Submerged forests, 95
Subsequent rivers, 152
Subsoil, 161
Sudan type, 170
Sulphur, 73, 76
Sulphur dioxide, 23
Sulphuric acid. 23
Sulphurous acid, 23
Summer rains climate, 171
Sun, 8
Sun, action of, 13
Sundarbans, 203
Superimposed drainage, 159
Superposition, law of, 53, 60
Surface currents, 189
Surrey, 153
Suspension, 27
Sussex, 153
Switzerland, 183
Swallow holes, 147
Syenite, 105
Symmetrical folds, 83
Syncline, 83, 84, 85
Synclinorium, 86

Tachylite, 103
Tarim Basin, 216
Tasmania, 179, 183
Tatra, 131
Taunton Deane, 238
Tea, 172
Temperature, atmospheric, 117 *et seq.*
Tension, 89
Terminal moraines, 55
Terraces, 155
Terrigenous deposits, 58
Tertiary, 194
Tertiary times, 208
Tetragonal, 110
Tetrahedral theory, 10
Texture of rocks, 97
Texture, soils, 163
Thalweg, 155
Thames, R., 62, 212
Thames Valley, 47
Thermometer, 118
Thrust Fault, 89
Thunderstorm rain, 128
Tibet, 14
Tidal scour, 37
Tides, 63, 190, 192
Tiger Hill, Darjeeling, 184–5
Tillites, 99
Time, geological, 195
Tin, 113
Tipheaps, 61
Tokyo, 79
Tor, granite, 109
Torrid Zone, 119
Torridonian sandstone, 197
Trachyte, 105
Trade Winds, 120
Trade Wind Belt, 175
Transhumance, 186
Transportation, 44 *et seq.*
Transverse valleys, 152
Tree-ferns, 203
Tree-frogs, 168
Tree-limit, 186
Tree-lizards, 168
Tremblement de terre, 77
Trent Valley, 233
Tremors, 77
Triassic Plain, 233
Triassic times, 204, 205
Triclinic, 110
Trilobites, 196
Trondheim, 57
Tropical climate, 169
Tropical soils, 161
Tropics, 119
Trough, 90, 142
Tufa, 102
Tuff, 106
Tuff cone, 68, 71
Tundras, 183, 186
Tundra soils, 162
Tweed Basin, 223
Typhoon, 17, 18, 190

Udi Plateau, 43
Ultra-basic, 105
Unconformity, 85, 95
Under-clay, 203
Undercutting, 36
Underground water, 160 *et seq.*
Under-saturated, 105
United States, 20, 44, 48, 177, 178
Unstable minerals, 111
Upthrow, 88
Uranus, 8
Urstromtäler, 56
U-shaped valleys, 30, 34

Vale of York, 233
Valleys, hanging, 30
Valparaiso, 79
Vegetation, 165 *et seq.*
Vegetation regions, 165 *et seq*
Veld, 170, 181
Velocity of stream, 29
Vein, 67, 68, 112
Vent, 68
Venus, 8
Vesuvius, 71, 72, 104, 105
Victoria Falls, 158
Vindhyan sandstones, 197
Vine, 176
Volcanic activity, 65
Volcanic ashes, 106
Volcanic rocks, 103
Volcanoes, 65 *et seq.*

Wales, 135, 202, 227
Wales, South, 136
Waterfalls, 155, 158
Watertable, 163
Waves, 34, 189
Waves, sand, 45
Weald, 153, 154, 242
Wealden dome, 210, 212
Wealden drainage, 154
Wealden lake, 207
Weather, 129
Weathering, 13 *et seq.*
Wegener, 10
Welsh Massif, 227
Westerlies, 121
Western Ghats, 128
Wexford, 248
Wheat, 179, 180
Whirlpool, 192
White mica, 111
Wicklow, 248
Wight, Isle of, 212, 242, 246
Wimbledon, 140
Wind, action of, 17, 44
Winds, 120 *et seq.*
Windward side, 128
Winter-rain Climate, 175
Wolds, 241
Wooldridge and Morgan, 9
World ocean, 187
Wrekin, 235

Yellowstone, 72, 75
Yokohama, 79
York moraine, 55
Yorkshire Dales, 237
York, Vale of, 128
Yorkshire, drainage, 139
Zakopane, 125, 131
Zinc, 113
Zinc Blende, 113
Zones, 119